US - EUROPEAN WORKSHOP

on

THERMAL WASTE TREATMENT FOR NAVAL VESSELS

Sponsored by the

United States Navy
Office of Naval Research European Office
and the
United States Army European Research Office

on 29-31 October 1997

at the
Sheraton Brussels Airport Hotel

Brussels, Belgium

organized by

Eule & Partners
International Consulting S.P.R.L.

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WORKSHOP PROCEEDINGS

of the

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The workshop objectives were:
· Discussion of current IMO-standards and the trend foreseen for the future
· Discussion of policies for IMO compliance by the US and European Navies
· Discussion of advanced incineration technologies, plasma treatment technologies, and supercritical water oxidation technologies
· Discussion and summary of development risks for the different thermal waste treatment systems under consideration and future research and technical reasons, why some countries use and other countries don't use state-of-the-art incineration
· Discussion and summary of adaptation of current and future thermal treatment technologies for development of Naval ship board waste treatment systems (including next generation of ships and platforms)
· Discussion and development of recommendations to industries and governments for policies and international collaboration potential
· Exhibition of thermal waste treatment technologies applicable to a ship board employment by Industry.

50 Professionals in this field from Industry, Governments and Universities attended the Workshop. Deerberg Systems, Oldenburg, Germany exhibited a display of its MULTIPURPOSE WASTE MANAGMENT SYSTEM.

14. SUBJECT TERMS
Waste Treatment Policies, Advanced Incineration Technologies, Plasma Treatment Technologies, Supercritical Water Oxidation Technologies

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Naval Surface Warfare Center Carderock Division, USA

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by **Dr. Eugene Nolting**, Naval Surface Warfare Center Carderock Division, USA

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Report
Chairman: Christoph Otten
Office of Military Technology and Procurement, Germany

d. **Working Group 3**: Policies and recommendations on international collaboration
Report
Chairman: Dr. Kevin Whiting
Environmental Technology Consulting, UK

9. List of Workshop Delegates

Summary Report

Summary Report on the Workshop on "THERMAL WASTE TREATMENT ON NAVAL VESSELS"

The Workshop on **"THERMAL WASTE TREATMENT ON NAVAL VESSELS"** was held on 29 – 31 October 1997 in conjunction with the subsequent meeting of NATO Special Working Group 12 on MARITIME ENVIRONMENTAL PROTECTION at the Sheraton Airport Hotel Brussels.

The purpose of the workshop was to provide the US Navy and other NATO Navies with the latest information about ongoing research and development in the area of thermal waste treatment and to create a professional forum for discussion of how these technologies may be applied to current and future Naval vessels. This included deliberations of trends of the pertinent IMO regulations.

The workshop aimed at producing recommendations for the navies as well as Universities and Industry on trends and requirements for the particular application of emerging thermal waste treatment technologies for naval vessels.

The workshop had been initiated by Dr I. Vodyanoy, ONR Europe and Mr. K. Schadow, NAWC China Lake, and was sponsored by ONR Europe and the US Army European Research Office. It was organized by Klaus D. Eule, Eule & Partners International Consulting S.P.R.L., Brussels.

Dr. Igor Vodyanoy, ONREUR, chaired the workshop

The workshop objectives were:

- Discussion of current IMO-standards and the trend foreseen for the future
- Discussion of policies for IMO compliance by the US and European Navies
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50 Professionals in this field from Industry, Governments and Universities attended the Workshop. Deerberg Systems, Oldenburg, Germany exhibited a display of its MULTIPURPOSE WASTE MANAGEMENT SYSTEM.

A keynote address was given by

Mr. Larry Koss
Chief Ship & Air Branch Environmental Protection Safety
& Occupational Health Division (N45)
Chief of Naval Operations
WASHINGTON, DC 20350-2000
United States,

who is the Chairman of NATO Special Working Group 12 on MARITIME ENVIRONMENTAL PROTECTION. He outlined the objectives and current constraints to achieve the „Environmentally Sound Ship of the 21st Century". He made a plea for a united effort by all players in this field to reach this goal as quickly as possible.

The workshop was organized in 5 Sessions

SESSION 1 - Waste Treatment Policies

Chairman: Jorgen Kyed, TeamTec, N-4900 Tvedestrand, Norway

SESSION 2 - Advanced Incineration Technologies

Chairman: Dr. Kevin Whiting, Environmental Technology Consulting, West Sussex, United Kingdom

SESSION 3 - Plasma Treatment Technologies

Chairman: Mr. Gene Nolting, Naval Surface Warfare Center, Bethesda, MD, USA

SESSION 4 - Supercritical Water Oxidation Technologies

Chairman: Jean-Roger Guichard, Compagnie Européenne d`Etudes en Environnement Industriel - C3EI, F-13100 Aix-en Provence, France

SESSION 5 - Working Groups

Working Group 1: Technical risk assessment and future research
Chairman: Dr. William Randall Seeker, Energy & Environmental Research Corp., USA

Working Group 2: Adaptation of current and future technologies to naval vessels
Chairman: Christoph Otten, Office of Military Technology and Procurement, Germany

Working Group 3: Policies and recommendations on international collaboration
Chairman: Dr. Kevin Whiting, Environmental Technology Consulting, UK

The Chairmen for the Policy and Technical Sessions provided an introductory overview of their specific area of interest before the Speakers for the different sessions from Industry, Government and Academia presented their papers on their specific topics.

The theme of Session 1 set the stage for the workshop by providing information on the latest status and future trends of the applicable policies and international regulations. This was followed by papers on the US Navy and German Navy position with regard to compliance with national and international regulations and the application of thermal waste treatment technologies aboard ships.

This session created the necessary focus on the issues pertaining to naval shipboard applications.

Sessions 2, 3 and 4 were Technology Sessions. They aimed at providing an overview of the three main thermal waste treatment technology areas, i.e. Advanced Incineration, Plasma Treatment and Super Critical Water Oxidation, to be followed by papers on the current state of research and development in the different areas. Altogether they offered an excellent review of the work conducted in this field applying the viewpoints of different disciplines, such as research, technology development and systems engineering.

These four sessions, which were held during the first two days of the workshop, laid the groundwork for the individual Working Group (WG) Sessions on the third day. Each WG consisted of about 15 delegates, who discussed Thermal Waste Treatment Technologies for Naval Vessels each under a different aspect, i.e. risk assessment and future research, adaptation of the technology to naval vessels and policies and recommendations for international collaboration.

The WG results were brought together in plenary session at the end of the workshop. A number of conclusions were drawn and several recommendations made both to NATO SWG/12, i.e. the Government Representatives present, and the Industry and Academia Representatives at the workshop.

In summary, the Working Groups established, that

- thermal waste treatment technology is available with varying degrees of maturity,
- international regulations will continue to evolve ever more stringent as technology matures, however individual port regulations will develop in a rather more diversified manner, making it difficult to comply and to retain operational freedom,
- naval vessels have special requirements regarding technology application and integration,
- manning, mission, availability, reliability and safety aspects will be drivers for the technology development,
- collaborative development of novel thermal waste treatment technologies and systems is worth pursuing by NATO Navies,
- regular workshops, like this one, should be held to increase and broaden the information exchange between the customer navies and producers and system integrators.

Organizationally and socially the workshop went very well. The Sheraton Brussels Airport Hotel offered a complete seminar package and provided excellent meeting room facilities. The new Business Centre in the Hotel supported the workshop by its availability of PCs, fax- and copy facilities. The Hotel is very conveniently located for this purpose, as it can be reached by the airport train from the City running every 15 min.

The social events, i.e. a reception hosted by the Organizer and an informal no-host dinner, offered many opportunities for discussions amongst the Delegates. These were continued over the luncheons during the workshop session days and have resulted in several new teaming arrangements between companies from different countries and also with Government and NATO officials.

In summary the workshop was received extremely well by the Delegates, who expressed their desire, that it may be repeated and perhaps be established as periodic event.

Workshop Objectives

In conjunction with the next meeting of **NATO Special Working Group 12** on

MARITIME ENVIRONMENTAL PROTECTION

the Office of Naval Research Europe is sponsoring a Workshop on

"THERMAL WASTE TREATMENT ON NAVAL VESSELS"

WORKSHOP OBJECTIVES:

- Discussion of current IMO-standards and the trend foreseen for the future
- Discussion of policies for IMO compliance by the US and European Navies
- Discussion of advanced incineration technologies, plasma treatment technologies, and supercritical water oxidation technologies
- Discussion and summary of development risks for the different thermal waste treatment systems under consideration and future research and technical reasons, why some countries use and other countries don't use state-of-the-art incineration
- Discussion and summary of adaptation of current and future thermal treatment technologies for development of Naval ship board waste treatment systems (including next generation of ships and platforms)
- Discussion and development of recommendations to industries and governments for policies and international collaboration potential
- Exhibition of thermal waste treatment technologies applicable to a ship board employment by Industry.

Workshop Agenda

Programme

Chairman : **Dr. Igor Vodyanoy**, ONREUR, Associate Director Biophysics

Wednesday, 29 October 1997

09.00 Check-in of Delegates, Administrative Matters

10:00-10:15 **Welcome & Introduction** by the Chairman

10.15-10.30 **Keynote Address**
by **Larry Koss**,
Chief Ship & Air Branch Environmental Protection Safety & Occupational Health Division,
Chief of Naval Operations, US Navy

10:30-12:45 **SESSION 1 - Waste Treatment Policies**

Chairman: Jorgen Kjed, TeamTec, Norway

10.30-11.15 Overview of MARPOL Regulations and Trends for Future Shipboard Requirements
by **Jorgen Kjed**, TeamTec, Norway

11.15-12.00 US Navy Response to Environmental Regulations
by **Craig Alig**, Naval Surface Warfare Center Carderock Division, USA

12.00-12.45 Current German Navy Position on Thermal Waste Treatment aboard New Construction Vessels
by **Christoph Otten**, BWB, Germany

12.45-14.00 Lunch, Exhibition is opened

14.00-17:30 **SESSION 2 - Advanced Incineration Technologies**

Chairman: Dr. Kevin Whiting,
Environmental Technology Consultant, United Kingdom

14.00-14-45 An Overview of Shipboard Solid Waste Disposal – the Past, the Present & the Future?
by **Dr. Kevin Whiting**, Environmental Technology Consultant, United Kingdom

14.45-15.30	Adaptation of Waste Management Systems by the International Navies by **Jochen Deerberg**, Deerberg Systems, Germany and **Klaus Schmidt**, CNIM, France
15.30-16.00	Coffeebreak
16.00-16.45	Advanced Combustion and Combustion Control for Small Incinerators by **Jan Sandviknes**, Norsk Energi, Norway
16.45-17.30	R & D in the United States on Incineration of Marine Waste by **Dr. Randy Seeker,** Energy and Environmental Research Corporation, USA and Shipboard Liquid Waste Thermal Destruction by **Carl M. Adema**, Naval Surface Warfare Center Carderock Division, USA
17.30-17.45	Discussion
18:00-20:00	Exhibition and Reception

Thursday, 30 October 1997

09:00-12:30	<u>SESSION 3</u> - **Plasma Treatment Technologies**
Chairman:	**Dr. Eugene Nolting,** Naval Surface Warfare Center Carderock Division, USA
09.00-09.45	Development of a Plasma Arc System for the Destruction of Waste aboard US Navy Warships by **Dr. Eugene Nolting**, Naval Surface Warfare Center Carderock Division, USA
09.45-10.30	Plasma Devices for Use in Effluent Gas Clean-up by **Dr. Norman Jorgensen**, AEA Technology, United Kingdom
10.30-11.00	Coffeebreak
11.00-11.45	The Equipment and Technology of Sanitation and Ecological Cleaning of Ships and Water Areas by **Dr. Adam M. Gonopolski** and **Dr. Tengiz N. Borisov**, Plasma-Test, Russia
11.45-12.30	Treatment of Naval Shipboard Waste Using a Plasma Arc Waste Treatment System by **Tim Rivers**, MSE Technology Application Inc., USA

12.30-12.45	Discussion
12.45-14.00	Lunch and Exhibition

14:00-17:30 <u>SESSION 4</u> - **Supercritical Water Oxidation Technologies**

Chairman: **Jean-Roger Guichard,**
Compagnie Européenne d'Etudes en Environnement Industriel - C3EI, France

14.00-14.45	Overview of Technologies Using Sub- or Supercritical Water Oxidation by **Jean-Roger Guichard,** Compagnie Européenne d'Etudes en Environnement Industriel - C3EI, France
14.45-15.30	SCWO Process Development at Forschungszentrum Karlsruhe by **Dr. Helmut Schmieder**, Forschungszentrum Karlsruhe, Germany
15.30-16.00	Coffeebreak
16.00-16.45	Use of Supercritical Water Oxidation for the On-Board Treatment of Naval Excess Hazardous Materials by **Dan D. Jensen**, General Atomics, USA
16.45-17.30	Hydrothermal Conversion of Wastes by **François Cansell**, University of Bordeaux, France
17.30-17.45	Discussion
19.30	Informal No-Host Dinner

Friday, 31 October 1997

09.00-12.00 <u>SESSION 5</u> - **Discussion in 3 Working Groups**

<u>Working Group 1</u>: Technical risk assessment and future research
<u>Chairman</u>: **Dr. William Randall Seeker**
Energy & Environmental Research Corp., USA

<u>Working Group 2</u>: Adaptation of current and future technologies to naval vessels
<u>Chairman</u>: **Christoph Otten**
Office of Military Technology and Procurement, Germany

<u>Working Group 3</u>: Policies and recommendations on international collaboration
<u>Chairman</u>: **Dr. Kevin Whiting**
Environmental Technology Consulting, UK

12.00-12.45 Working Groups preparation of reports

12.45-14.00	Lunch
14.00-15.00	Plenary Meeting; Working Groups summary presentations
15.00-15.15	Workshop Summary and Closing Remarks by the Chairman

Keynote Address

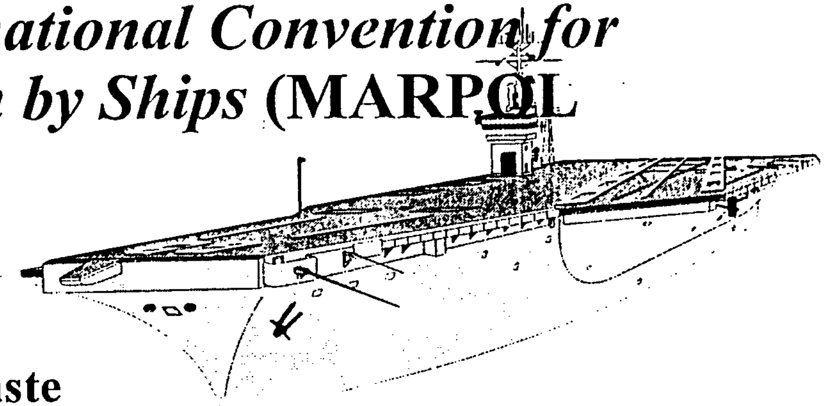
by **Larry Koss**

Chief Ship & Air Branch Environmental Protection Safety
& Occupational Health Division,
Chief of Naval Operations, US Navy

SWG/12
Maritime Environmental Protection

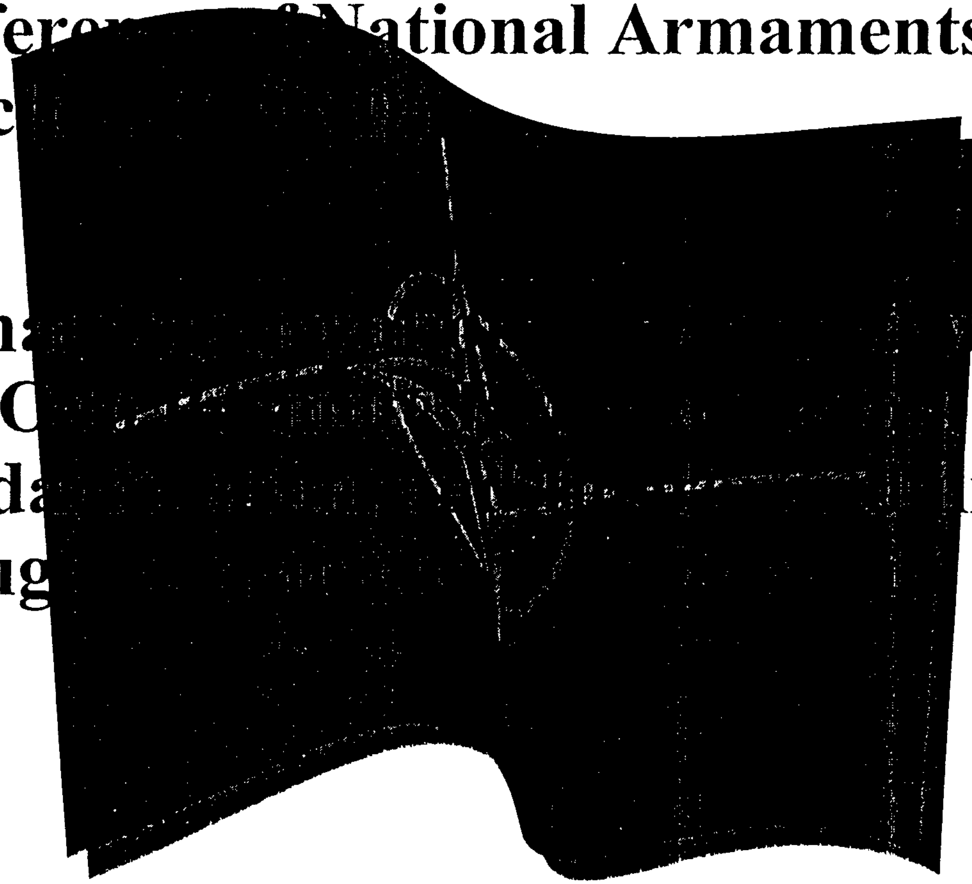
IMO & MARPOL 73/78

- International Maritime Organization (IMO) Is Forum For International Agreements Affecting Maritime Industry (Individual Nations Then Ratify as National Law)
- Pollution Control = *International Convention for the Prevention of Pollution by Ships* (MARPOL 73/78)
  - Annex I -- Oil Pollution
  - Annex IV -- Sewage
  - Annex V -- Solid & Plastics Waste
  - Annex VI - Air Pollution
- MARPOL Actually Excludes Public Vessels, But Many Nations Expect Their Naval Vessels to Comply



Armaments Cooperation in NATO

- **Confer... National Armaments Direc...**



- **Form... within NATO... Standa... ity throug...**

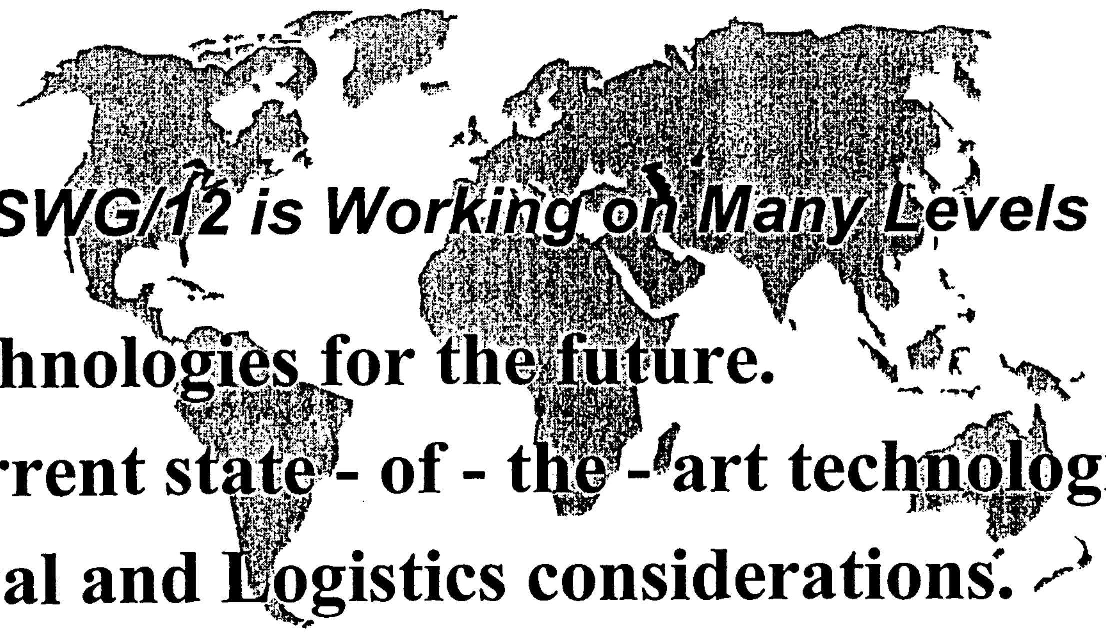
Special Working Group 12 (SWG/12) Maritime Environmental Protection

- ❖ Established by NATO to Pursue Environmentally Sound Ships
  - ➢ RDT&E
  - ➢ Ship Design
  - ➢ Logistics
- ❖ 13 Nations Participating
  - ➢ BE, CA, DN, FR, GE, GR, IT, NL, NO, PO, SP, UK, US

SWG/12 Terms of Reference

"To promote, through information exchange, the development of capabilities among NATO navies to comply with national and international maritime environmental protection regulations, and to foster cooperative efforts for achieving environmentally sound ships and support facilities."

Maritime Environmental Protection



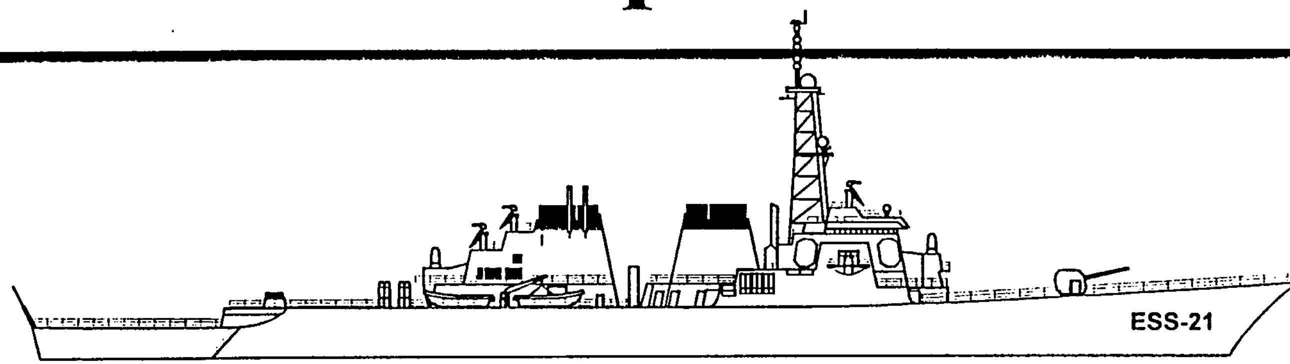
SWG/12 is Working on Many Levels

- Technologies for the future.
- Current state - of - the - art technologies.
- Legal and Logistics considerations.
- Total integrated ship/shore environmental protection systems.

What Are The Trends?

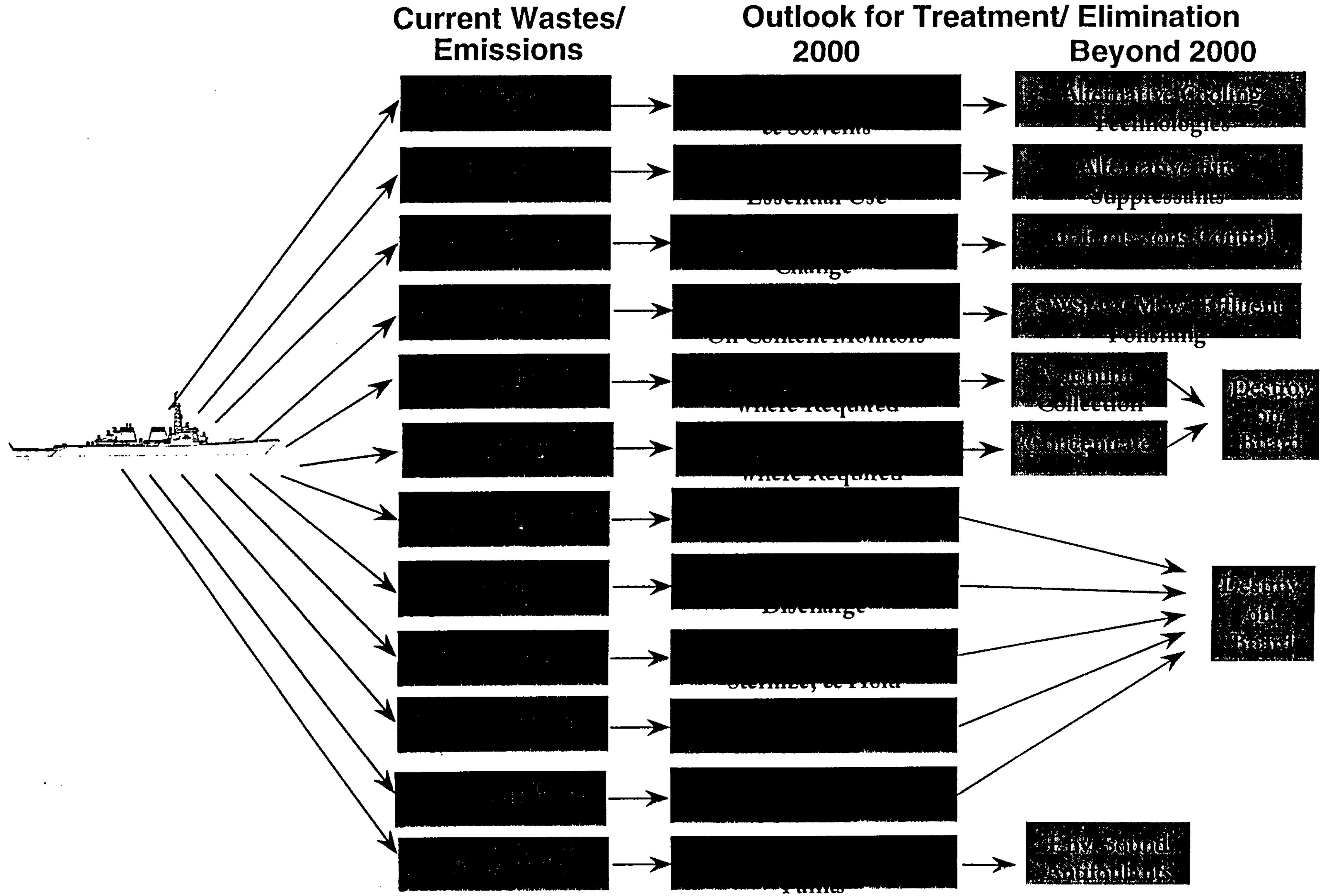
- NATO Navies Generally Required To Comply With MARPOL By Law, Regulation, Or Policy
- Equipment Backfit Is Expensive
- Waste Off-Load Costs Increasing
- General Agreement That Navies Must Be Environmental Leaders
- Share A Common Vision Of Environmentally Sound Ships

What Do We Mean by
"Environmentally Sound Ships?"



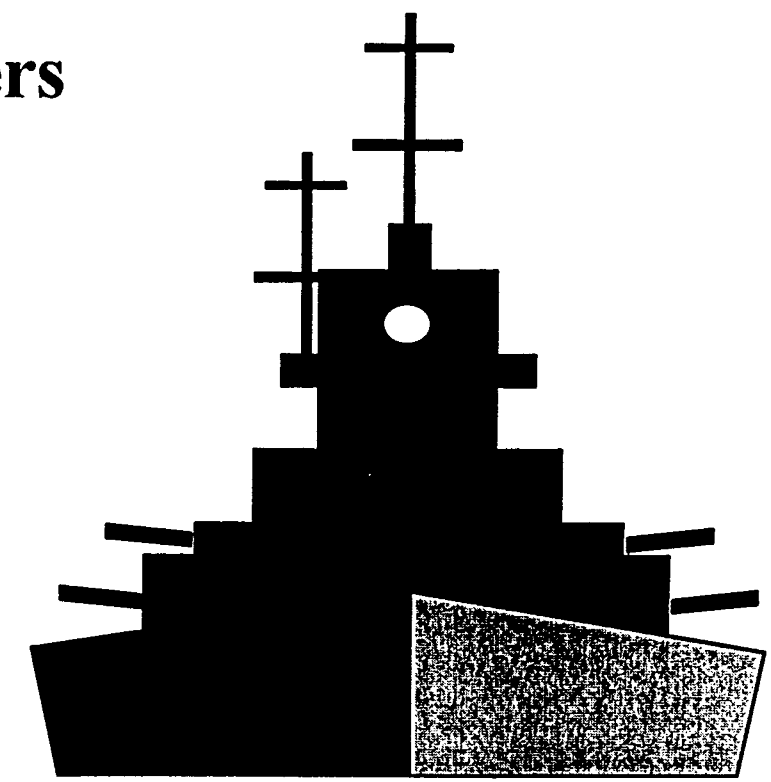
- ❖ **All waste streams sufficiently treated or destroyed on board ship:**
  - ➢ **processed waste can be discharged or released without harm to the environment; or**
  - ➢ **returned to shore for recycling or disposal**
- ❖ **Compliance with environmental regulations**
- ❖ **Minimum use of hazardous materials**
- ❖ **Totally integrated "Green Ship" design**

NATO Strategy to Achieve Environmentally Sound Ships



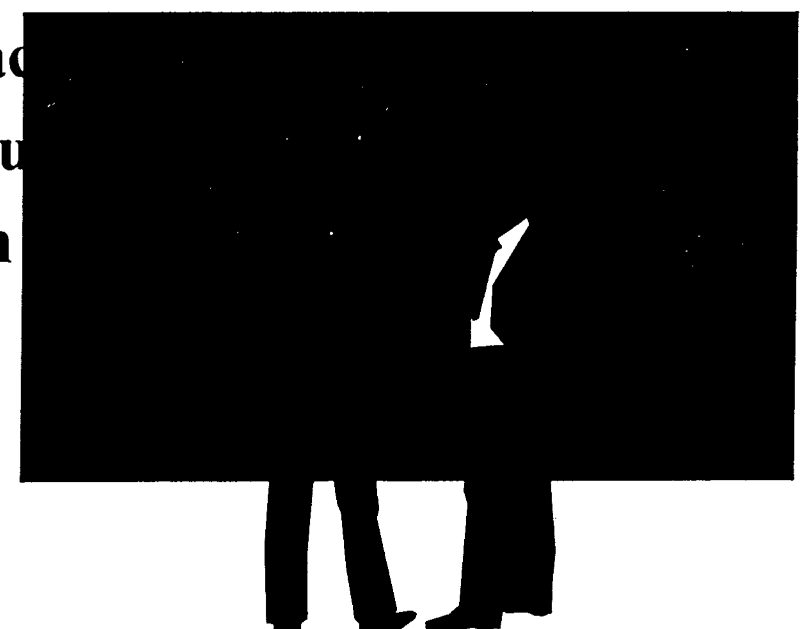
Ships are Warfighters !

- ❖ Minesweepers
- ❖ Cruisers and Destroyers
- ❖ Amphibious Ships
- ❖ Aircraft Carriers



Where Do We Go?

- ❖ Worldwide Capability
- ❖ Blue Water to Littoral
  - ➢ North Sea and Baltic Sea
  - ➢ Mediterranean and Blac
  - ➢ Red Sea and Persian Gu
  - ➢ Atlantic and Caribbean



What Do We Do?

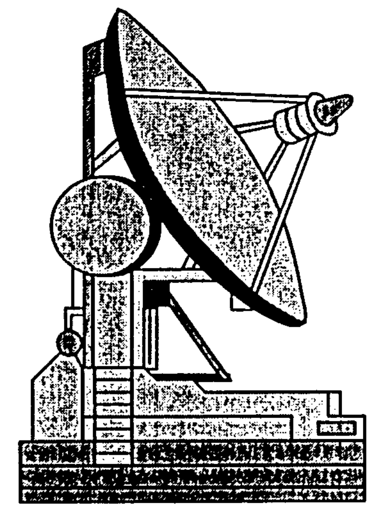
- Operations and Training
- Forward Presence
- Contingency Operations
- Combat Operations
- Port Visits

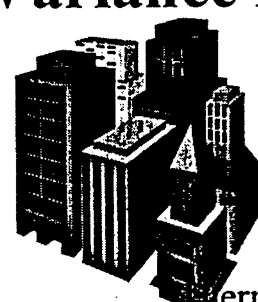
What is the Problem?

- Environmental Regulations Can Constrain Operations
- MARPOL 73/78
  - Annex I - Oil Pollution
  - Annex IV - Sewage (not in effect)
  - Annex V - Solid Waste
  - Annex VI - Air Pollution (not in effect)
- Warships are Exempt but Nations Expect Compliance
  - Commanding Officer Responsibility

Navy Ships are Unique!

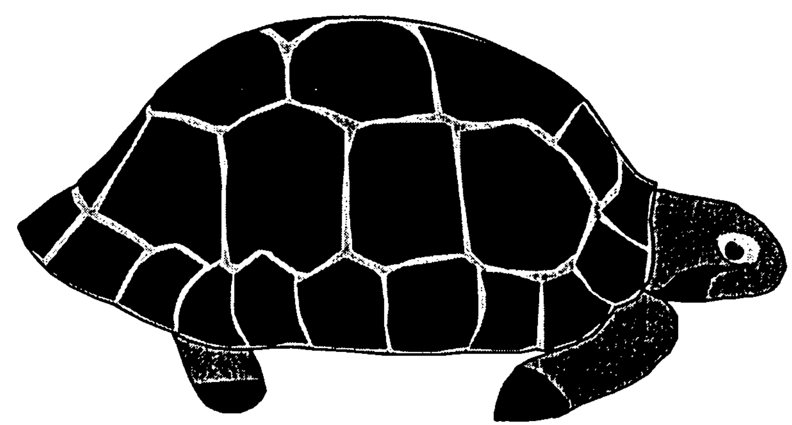
- Designed for Military Missions
  - Complex Weapon Systems
  - 30 to 50 Years in Service
- Long Mission Duration
  - Yet Significant Time in Port
- Small Cities
  - Daily Variance in Waste Composition





What are the Needs?

- Environmentally Sound Ships
  - Affordable Compliance Today and Tomorrow
- Destroy Waste on Board
- Benign Discharges



What are the Constraints?

- Systems must be:
  - Safe and Reliable
  - Maintainable
  - Compact
  - Automated
  - Modular
  - Low Signature
  - Robust
  - Affordable

Why Thermal Destruction?

- Only Technologies that Show Promise to Destroy Wastes on Board Navy Ships
  - Recommended by NIAG and DRG Studies
- Thermal Technologies Under Consideration Include:
  - Conventional and Advanced Incineration
  - Plasma Arc
  - Hydro-Thermal Oxidation
  - Molten Metal and Molten Salt

Pushing the Envelope!

- High Capacity
- Benign Air Emissions
- Low Thermal and Electro-Magnetic Signature
- Withstand Shock and Vibration
- Capable of Operation in a Seaway

Challenges and Opportunities!

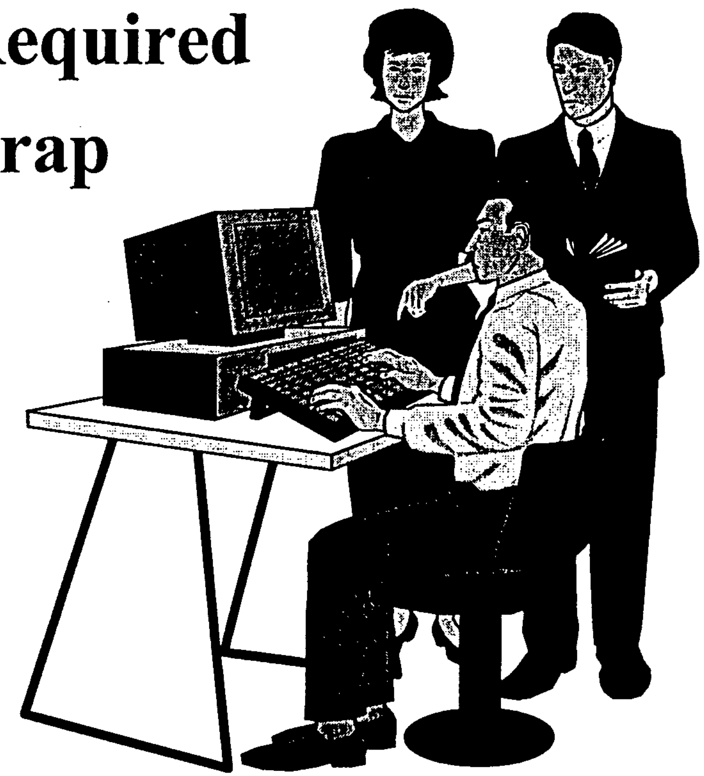
- Need High Through-Put, Compact, Automated Systems
- Systems Must be Reliable
- Systems Must be Maintainable
- Systems Must not Require Extensive Operator or Maintainer Training

Potential Markets!

- Ship Systems
  - NATO Navies
  - Other Navies
  - Cruise Lines
- Portable Land System?
  - Island Nations
  - Emerging Democracies

We Need You!

- Experts Must Push the Envelope
- Technical Advances Required
- Build a Better Mousetrap



Affordability is Key

- All Navies Facing Similar Challenges
- Declining Defense Budgets
- We Must Cooperate To Comply with Existing and Future Regulations in an Affordable Manner
  - Leverage International Technology Investment
  - Avoid Duplication of Effort
  - Achieve Economies of Scale
  - Employ Dual Use Technologies

Session 1 - Waste Treatment Policies

Chairman: Jorgen Kyed, TeamTec, Norway

Overview of MARPOL Regulations and Trends for Future Shipboard Requirements

TeamTec
MARINE PRODUCTS

SAVE OUR OCEANS

THEY ARE "DROWNING" IN GARBAGE AND WASTE

For thousands of years the vastness of the oceans has contributed to the belief that they are an ideal repository for waste from man's activities.
Today we know that a continuing accumulation of waste is polluting the sea itself, its beaches and seabed.
And the world has become concerned!

Since ancient times all shipboard waste have been dumped overboard. In modern times the shipping industry has become a major contributor to the pollution of our oceans and coastal waters. This is no longer tolerated. International regulations have been established to control:

WASTE DISPOSAL ON BOARD SHIPS

IMO - INTERNATIONAL MARITIME ORGANIZATION

REGULATIONS FOR WASTE DISPOSAL ON BOARD COMMERCIAL SHIPS

WASTE DISPOSAL ON BOARD COMMERCIAL SHIPS

Dumping of waste into the sea and air pollution is regulated world wide by :

THE IMO MARPOL 1973/78/79 REGULATIONS FOR THE PREVENTION OF POLLUTION FROM SHIPS :

ANNEX I : **REGULATIONS FOR PREVENTION OF POLLUTION BY OIL**

ANNEX II : **REGULATIONS FOR THE CONTROL OF POLLUTION BY NOXIOUS LIQUID SUBSTANCES IN BULK**

ANNEX III : **REGULATIONS FOR THE PREVENTION OF POLLUTION BY HARMFUL SUBSTANCES CARRIED BY SEA IN PACKAGED FORMS, OR IN FREIGHT CONTAINERS, PORTABLE TANKS OR ROAD OR RAIL TANK WAGONS**

ANNEX IV : **REGULATIONS FOR THE PREVENTION OF POLLUTION BY SEWAGE FROM SHIPS**

ANNEX V : **REGULATIONS FOR THE PREVENTION OF POLLUTION BY GARBAGE FROM SHIPS**

ANNEX VI : **REGULATIONS FOR THE PREVENTION OF AIR POLLUTION FROM SHIPS**

Generally speaking it is prohibited to dump into the sea any material of category : ANNEX I, II, AND III.

For materials under ANNEX V, please see the following : EXCERPT OF MARPOL ANNEX V.

TeamTec
MARINE PRODUCTS

Excerpt of MARPOL ANNEX V Garbage Disposal Limitations

Garbage Type	All vessels		Offshore Platforms & Assoc. Vessels
	Outside Special Areas	..In Special Areas	
Plastics. includes synthetic ropes and fishing nets and plastic garbage bags	Disposal prohibited	Disposal prohibited	Disposal prohibited
Floating dunnage, lining and packing materials	>25 miles off shore	Disposal prohibited	Disposal prohibited
Paper, rags, glass, metal bottles, crockery and similar refuse	>12 miles	Disposal prohibited	Disposal prohibited
Paper, rags, glass etc. comminuted or ground	> 3 miles	Disposal prohibited	Disposal prohibited
Food waste not comminuted or ground	>12 miles	12 miles	Disposal prohibited
Food waste comminuted or ground	> 3 miles	12 miles	Disposal prohibited
Mixed refuse types	*	*	Disposal prohibited

Comminuted or ground garbage must be able to pass through a screen with mesh size no larger than 25 mm.

Offshore platforms and associated vessels includes all fixed or floating platforms engaged in exploration or exploitation of seabed mineral resources, and all vessels alongside or within 500 m of such platforms.

* When garbage is mixed having different disposal or discharge requirements the more stringent disposal requirements shall apply.

<u>IT IS PROHIBITED TO DUMP INTO THE SEA :</u>

ANY MATERIAL OF CATEGORY

ANNEX I, II AND III

ANY WASTE CONTAINING PLASTIC OR SYNTHETIC MATERIALS

<u>IN SPECIAL AREAS :</u>

ALL WASTE DISPOSAL IS PROHIBITED

- EXCEPT FOOD WASTE WHEN THE VESSEL IS 12 MILES OFF NEAREST LAND

Planned or declared special areas are

THE NORTH SEA
THE BALTIC SEA
THE MEDITERRANEAN
THE BLACK SEA
THE RED SEA
THE ARABIAN GULF
THE CARIBBEAN

In addition to the IMO MARPOL REGULATIONS there are of course also rules and regulations instituted by Coastal States and Port Authorities.

For the worlds commercial and fishing fleets waste disposal is a huge problem.

In many ports around the world shore reception facilities are nonexistent.

In other ports solid garbage and waste is dumped in a landfill.

Polluting ground water, spreading deceases, atracting rats. And emiting methane gas which is very destructive to the ozone layer.

In other places waste is simply burned in open pits, producing <u>immense</u> air pollution!

To give an idea of the volume of operational waste generated on board ships one may look at some statistics and estimatd figures :

ACCORDING TO LLOYD'S REGISTER OF SHIPPING, JANUARY 1. 1995 THE WORLDS COMMERCIAL FLEETS CONSISTED OF THE FOLLOWING :

COMMERCIAL SHIPS above 100 GRT		:	<u>83.645 Vessels</u>
Totalling :	494.357.529 GRT.		
	741.466.407 DWT		
FISHING VESSELS		:	<u>23.000 Vessels</u>

ESTIMATED CREW :	ABOUT 2.782.000 PERSONS
PLUSS ABOUT :	116.000 PASSENGERS ON BOARD CRUISE SHIPS
TOTAL :	<u>2.898.000 PERSONS</u>

TeamTec
MARINE PRODUCTS

NOT INCLUDED IN ABOVE FIGS. :

CREWS ON BOARD SHIPS OF LESS THAN 100 GRT.
CREWS ON BOARD NAVY SHIPS
PASSENGERS ON FERRIES

ESTIMATED AVERAGE QUANTITIES OF DAILY GENERATED OPERATIONAL WASTE ON BOARD COMMERCIAL SHIPS

AA.	Food waste :	0,6 kg per man/day	x 1.400 kcal
BB.	Rubbish :	1 kg per man/day	x 5.000 kcal
CC.	Waste oil :	4 - 20 kg/day	x 8.000 kcal
DD.	Sludge oil :	1 percent of fuel cons.	x 7.000 kcal
EE.	Sewage sludge :	0,2 - 2 kg per man/day	No heat value

FOR SPECIAL VESSELS.
AND
FOR PASS/CRUISE SHIPS FOOD WASTE AND RUBBISH FIGS.
MAY BE 30 TO 50% HIGHER.

DAILY WASTE GENERATION

Food waste	2.782.125 x 0,6 =	1.669.275 kg
Rubbish	2.782.125 x 1,0 =	2.782.125 kg

Total : 4.451.400 kg
or : 4.451 tons

Annual :4.451 x 365 = 1.624.615 TONS

ANNUAL (HFO) BUNKER FUEL
CONSUMPTION WORLD WIDE

≈ 150.000.000 TONS

OF THIS ABOUT 140.000 000 TONS IS CONSUMED BY DIESEL POWERED SHIPS.

SLUDGE OIL FROM HFO ON DIESEL POWERED SHIPS :
140.000.000 x 0.01 = 1.400.000 TONS

ESTIMATED AMOUNT OF WASTE LUB. OIL:
106.645 vessels x 10 l/day x 365
≈ 389.000 TONS/YEAR

So the commercial shipping and fishing fleets have a waste problem to handle amounting to a minimum of

≈ 3.413.000 TONS PER YEAR!

There is a general understanding in imo that when enforcing new regulations against pollution this should not be done in a way which put unnessessary high economic burdens on the shipping industry.

COST EFFECTIVE

Is a word much used in IMO.

It has been realized that for sea going ships the most practical and economical solution for disposal of both sludge oil and solid waste is

ON BOARD INCINERATION

This is probably also environmentally the best solution.

Avoiding the problems with poor land disposals.

Avoiding long trucking and/or barge transports in dence populated areas.

Avoiding delays of vessels in harbours, with thereof following extra fuel consumption.

IMO REQUIREMENTS TO INCINERATOR

RESOLUTION MEPC.59(33)
ADOPTED ON 30 OCTOBER 1992

NOW REPLACED BY SLIGHTLY REVISED RESOLUTION MEPC 40.
ADOPTED 26. SEPTEMBER 1997

REVISED GUIDELINES FOR THE IMPLEMENTATION OF ANNEX V OF MARPOL 73/78

STANDARD SPECIFICATION FOR SHIPBOARD INCINERATORS

THE NEW IMO MARPOL ANNEX VI REQUIRE THAT
AFTER YEAR 2000 ALL NEW INCINERATORS MUST BE CERTIFIED IN COMPLIANCE WITH A.M. REGULATIONS.
THE USE OF OLD INCINERTORS HAVING NO IMO CERTIFICATE WILL BE RESTRICTED.

ANNEX VI EMISSION REQUIREMENT

REQUIRED EMISSION STANDARDS TO BE VERIFIED BY TYPE APPROVAL TEST

O_2 IN COMBUSTION CHAMBER	6 - 12 %
CO IN FLUE GAS MAXIMUM AVERAGE	200 mg/MJ
SOOT NUMBER MAXIMUM AVERAGE	BACHARACH 3 or RINGLEMAN 1 (A higher soot number is acceptable only during very short periods such as starting up)
UNBURNED COMPONENTS IN ASH RESIDUES	Max 10% by Weight
COMBUSTION CHAMBER FLUE GAS OUTLET TEMPERATURE RANGE	850 - 1200 °C

A HIGH TEMPERATURE IN THE ACTUAL COMBUSTION CHAMBER/ZONE IS AN ABSOLUTE REQUIREMENT IN ORDER TO OBTAIN A COMPLETE AND SMOKE FREE INCINERATION, INCLUDING THAT OF PLASTIC AND OTHER SYNTHETIC MATERIALS WHILE MINIMIZING **DIOXINE, and VOC** (Volatile Organic Compounds) EMISSIONS.

SHIPBOARD INCINERATION

WITH A MODERN MARINE INCINERATOR :
Certified in compliance with the IMO REGULATIONS.

AIR POLLUTION IS EXTREMELY LOW

On board a non-passenger ship when burning both sludge oil and all daily generated waste air pollution from the incinerator will amount to approx. 1 % of the total from main and aux. engines.

FURURE TREND

Practically all countries around the world have problems with waste disposal.

Today almost al new commercial ships are fitted with an incinerator.
One can expect that more and more operational shipboard waste will be incinerated on board.

This trend will, of course, ease the pressure on poor countries for investing in adequate shore reception facilities.

For the shipping companies on board incineration offers the most practical an economical solution.

COSTLY DISCHARGE OF SLUDGE OIL AND SOLID GARBAGE AND WASTE

A few ports, mainly in north west europe offer shore reception of sludge oil free of charge.

In most ports around the world it is very expensive.

As high as : U.S. Dollars 1,300.- per m^3.

Other examples are :

25 m^3 SLUDGE OIL

IN JAPAN :	USD 20,000.-
NEW ORLEANS :	USD 7,000.-
PANAMA CANAL :	USD 7,000.-

B.P. OIL COMPANY, U.S.A.
Reports :

Average cost for on shore disposal of solid waste only :

U.S. DOLLARS 3 - 5,000.- per ship/month

ADDITION OF ANNEX VI TO THE INTERNATIONAL CONVENTION FOR THE PREVENTION OF POLLUTION FROM SHIPS, 1993, AS MODIFIED BY THE PROTOCOL OF 1978 RELATING THERETO

The following new Annex VI added after the existing Annex V :

"ANNEX VI

REGULATIONS FOR THE CONTROL OF AIR POLLUTION FROM SHIPS

CHAPTER I - GENERAL

REGULATION 1

Application

The provisions of this Annex shall apply to all ships, except where expressly provided other wise in regulations 3, 5, 6, 13, 15, 18 and 19 of this Annex.

REGULATION 2

Definitions

REGULATION 3.:	GENERAL EXCEPTIONS
REGULATION 4.:	EQUIVALENTS
REGULATION 5.:	SURVEYS AND INSPECTIONS
REUGLATION 6.:	ISSUE OF INTERNATIONAL AIR POLLUTION CERTIFICATE
REGULATION 7.:	ISSUE OF A CERTIFICATE BY ANOTHER GOVERNMENT
REGULATION 8.:	FORM OF CERTIFICATE
REGULATION 9.:	DURATION AND VALIDITY OF CERTIFICATE
REGULATION 10.:	PORT STATE CONTROL ON OPERATIONAL REQUIREMENTS
REGULATION 11.:	DETECTION OF VIOLATIONS AND ENFORCEMENT
REGULATION 12.:	OZONE DEPLETING SUBSTANCES
REGULATION 13.:	NITROGEN OXIDES (NO_X)
REGULATION 14.:	SULPHUR OXIDES (SO_X)
REGULATION 15.:	VOLATILE ORGANIC COMPOUNDS

REGULATION 16.:	SHIPBOARD INCINERATORS
REGULATION 17.:	RECEPTION FACILITIES
REGULATION 18.:	FUEL OIL QUANTITY
REGULATION 19.:	REQUIREMENTS FOR PLATFORMS AND DRILLING RIGS

FUTURE REGULATIONS

One may expect that future reulations will require all sea going ships to be fitted with an incinerator.
At the same time there will probably be reduction in the volume of operational waste by reducing packing materials, etc.

Tvedestrand, 14th October 1997

Jorgen Kyed

<u>Session 1</u> - Waste Treatment Policies

US Navy Response to Environmental Regulations

by **Craig Alig**
Naval Surface Warfare Center Carderock Division, USA

U.S. Navy Response to Environmental Regulations

Mr. Craig Alig

October 1997

How Did We Get In This Mess?

- Clean Water Act - 1970's
- Emphasis on sewage
- Law gave the Navy authority to write the rule
- Exempted "discharges incidental to normal operations"
- Preempted State's ability to establish different criteria

How Did We Meet the Challenge?

- Market survey - no viable sewage treatment systems available to meet navy requirements
- Developed Collection, Holding, and Transfer (CHT) systems
  - Ship CHT systems
  - Shore reception facilities in Navy ports
- Backfit throughout the fleet at enormous expense

Commercial Off The Shelf (COTS)

- Testing revealed that most waste processing COTS systems were not robust enough to meet Navy requirements
- Problems included:
  - Shore technology not easily transferred to Navy ships
  - Daily fluctuations in the waste stream
  - Lack of dedicated professional operators
  - Operational profile - long periods at sea but also long periods in port

Along Comes MARPOL

- Navies exempt from compliance
  - Sovereign vessels
  - Recognized impact on mission capability
- Navies encouraged to comply as far as reasonable and practicable
- Domestic legislation required to implement MARPOL not anticipated to apply to the Navy, but....

5

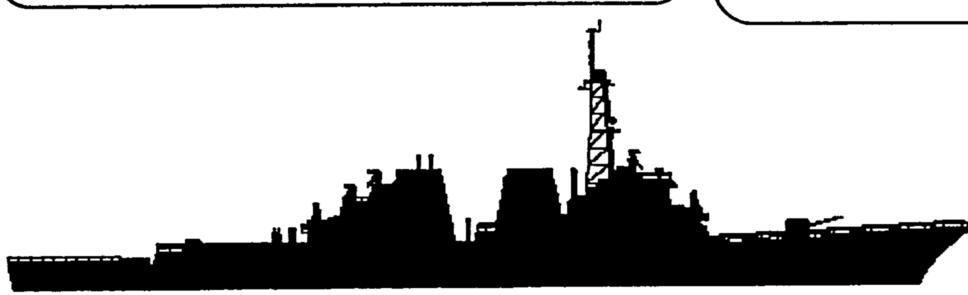
Major Environmental Laws

LIQUID WASTES (*bilgewater, ballastwater, waste oil, sewage, graywater, other*)
Clean Water Act
International Convention for the Prevention of Pollution from Ships, Annex I & proposed Annex IV
Act to Prevent Pollution from Ships
Oil Pollution Act
Section 325 of National Defense Authorization Act for FY96 (Uniform National Discharge Standards)

OZONE DEPLETING SUBSTANCES (*CFC refrigerants, CFC solvents, Halon firefighting agents*)
Montreal Protocol on Substances That Deplete the Ozone Layer (and subsequent amendments)
Clean Air Act Amendments of 1990
Executive Order 12843 (Federal procurement requirements)

HAZARDOUS MATERIALS
Clean Water Act
Resource Conservation & Recovery Act
Toxic Substances Control Act
Clean Air Act
Executive Order 12856 (pollution prevention)

SOLID WASTES (*plastics, paper, cardboard, metal, glass, textiles, other*)
Clean Water Act
International Convention for the Prevention of Pollution from Ships, Annex V
Act to Prevent Pollution from Ships
Marine Plastic Pollution Research & Control Act
Section 1003 of National Defense Authorization Act for FY94
Section 324 of National Defense Authorization Act for FY97



GENERAL
National Environmental Policy Act
Marine Mammal Protection Act
Endangered Species Act
National Marine Sanctuaries Act
Executive Order 12114 (environmental effects abroad)
State & local regulations
Foreign-country requirements

MEDICAL WASTES (*infectious, non-infectious*)
U.S. Public Vessel Medical Waste Anti-Dumping Act

07/28/97

Reasonable and Practicable

- Market survey - still no COTS equipment that will meet Navy requirements
- Problems include;
  - performance
  - reliability
  - maintainability
  - availability

Legal, Political, Logistic, RDT&E!

- Established the CNO vision of Environmentally Sound Ships
- Worked with Congress to get deadline extensions
- Met with stakeholders to learn their concerns and explain Navy constraints
- Began extensive RDT&E program
- Used shore infrastructure where possible and pay offload costs

Estimated Annual Fleet Waste Disposal Costs

$5M	Solid Wastes
$41M	Sewage & Graywater
$28M	Bilgewater
$1M	Compensated Fuel System Ballast Water
$17M	Hazardous Waste
$92M	Total

[redacted]

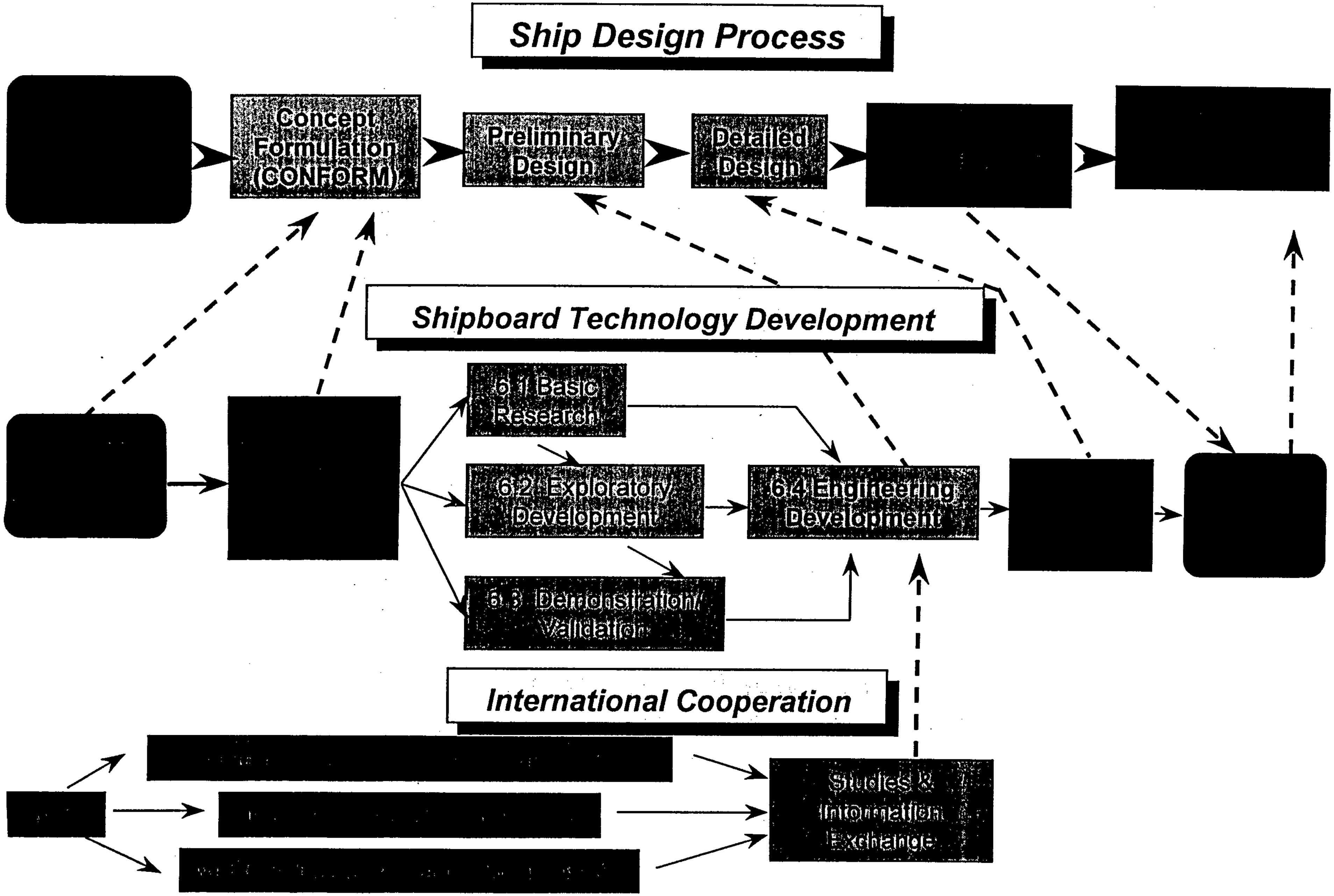
NOTE: Based on FY95 data

Operational Compliance in an Affordable Manner

- Legislative Solutions for Operational Necessity
  - Solid Waste (APPS)
  - Uniform Discharge Standards (UNDS)
  - Others - Air, Water...

- Technical Solutions for Operational Freedom
  - RDT&E / Advanced Technology - ESS-21
  - Invest to Reduce Total Navy Lifecycle Costs
- International Cooperation
  - NATO Armaments
  - Bi & Tri-lateral
  - Leverage Cooperation to Save Time and Money

ENVIRONMENTALLY SOUND SHIP: INTERDEPENDENCIES



CNO Vision for Environmentally Sound Ship of 21st Century

- New-design ships must be able to operate in U.S., international, & foreign waters without degradation of mission or quality of life attributable to environmental laws & regulations
- Ships must be designed & operated to minimize waste generation & optimize waste management
- Shipboard systems must be used to destroy or appropriately treat wastes generated onboard

Shipboard Waste Management RDT&E (6.4 Advanced Development)

GOAL IS TO DEVELOP SHIPBOARD EQUIPMENT, SYSTEMS, & PROCEDURES TO:

- ❖ Manage ship wastes in compliance with existing environmental restrictions worldwide without jeopardizing ship mission, survivability, or habitability
- ❖ Minimize the cost of Fleet environmental compliance

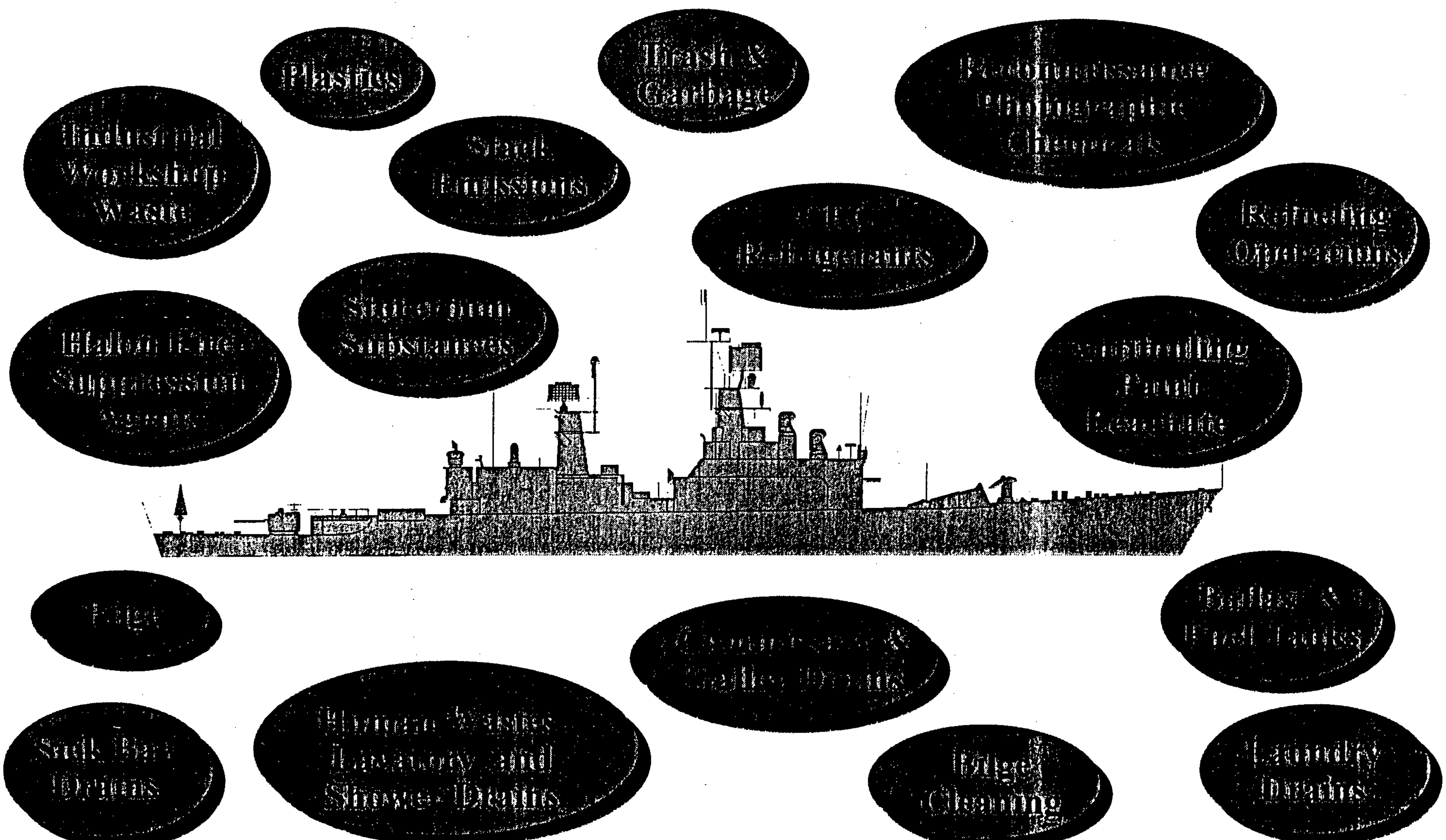
[redacted]

6.4 Advanced Development Challenges

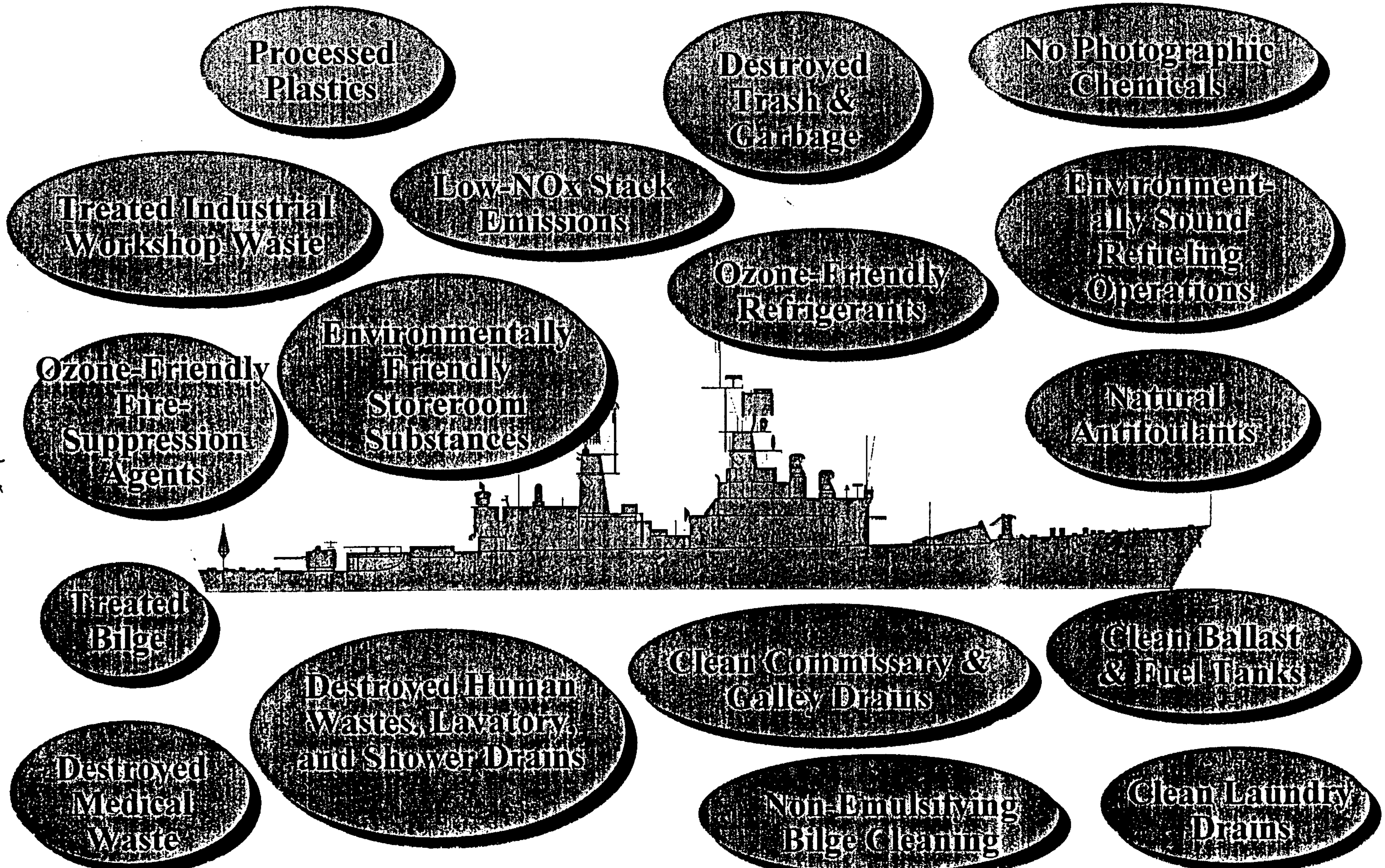
TO DEVELOP FULL-SCALE SHIPBOARD ENVIRONMENTAL SYSTEMS THAT:

- **Meet USN Shipboard Requirements**
  - **Performance, space, weight, shock, vibration, electromagnetic compatibility, noise & acoustics, etc.**
- **Are Reliable & Maintainable at Sea**
- **Impose No or Low Manning Requirement**
- **Incorporate Integrated Logistics Support**
- **Are Affordable**

Typical Ship "Pollution" Sources



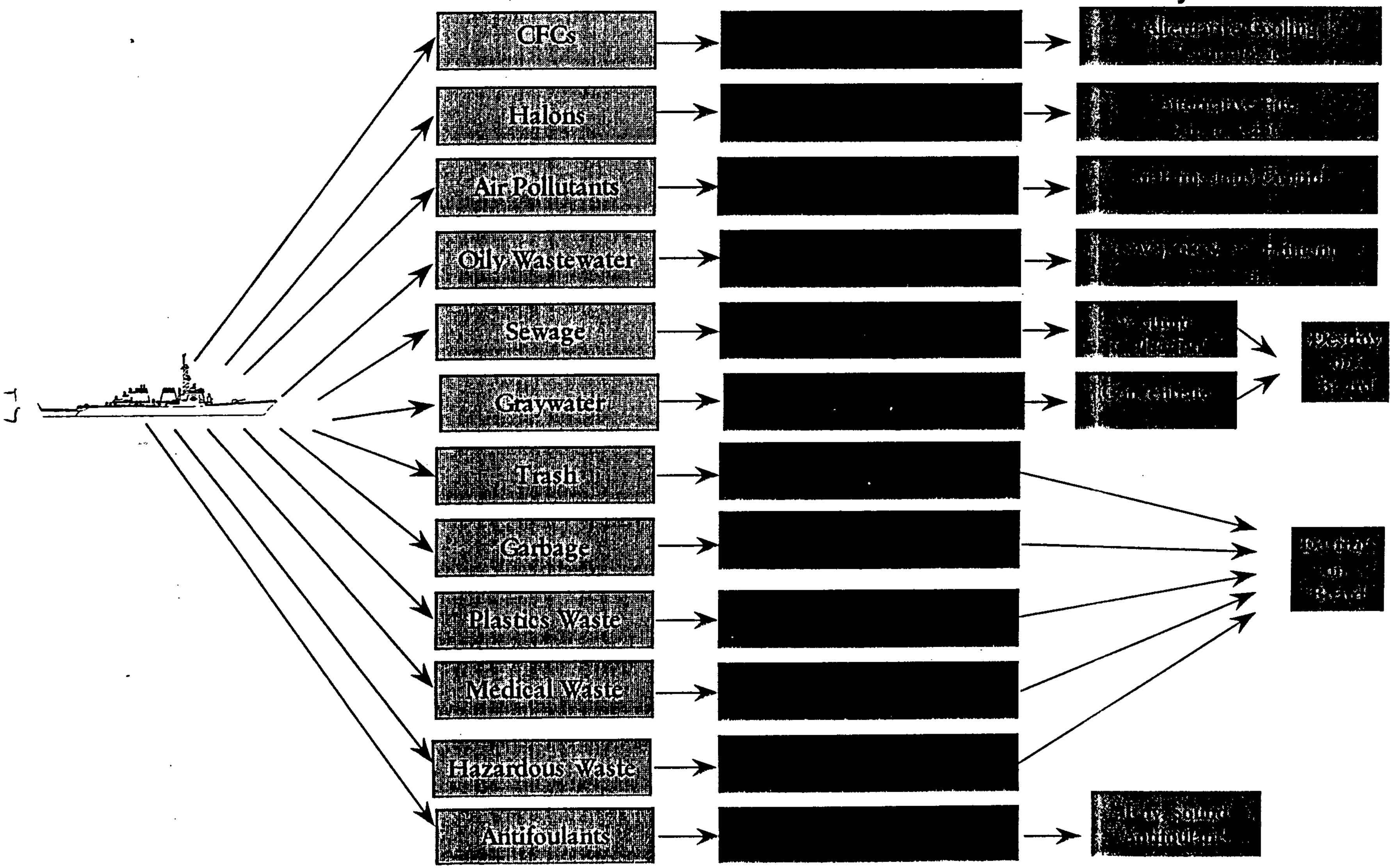
ESS-21 "Pollution" Solutions



Shipboard Pollution Abatement

Year 2000 and Beyond

Current Wastes/ Emissions | **Outlook for Treatment/ Elimination 2000** | **Beyond 2000**



Successful U.S. Developments...

- Plastics Waste Processors
- Oil/Water Separators
- Oil Content Monitors
- Sewage Vacuum Collection Systems
- Solid Waste Pulpers
- Metal and Glass Shredders
- Ozone-Depleting Substance Elimination
  - CFC-12 Refrigerant Alternatives
  - Refrigerant Recycling
  - Award-Winning Halon Recycling

...And Ongoing U.S. Efforts

- Oily Water Membrane Polishing Systems
- Blackwater / Graywater Treatment Systems
- Hazardous Waste Minimization: Paint Removal
- Advanced Thermal Destruction

Session 1 - Waste Treatment Policies

Current German Navy Position on Thermal Waste Treatment aboard New Construction Vessels

by Christoph Otten,
BWB, Germany

Current GE Navy Position on Thermal Waste Treatment aboard New Construction Vessels

Christoph Otten
Federal Office for Military Technology and Procurement
Germany

US-European Workshop on Thermal Waste Treatment for Naval Vessels
Brussels, 29-31 October 1997

BWB
SG III 3

Contents

1. Legislation and Policy

- GE Navy has to comply with national & international laws / conventions on MEP
  - -> no best effort clause
  - -> no exemptions
- GE Navy has itself committed to set a good example

Policy (cont'd)

Procurement policy MEP equipment:

- Integration of commercial equipment
- Adaptation, if necessary (e.g. landbased technology)
- Development (hardly ever)

2. Task Group Replenishment Ship Class 702

Operational Requirement

- Replenishment of a Task Force of up to 4 frigates for up to 45 days incl. solid waste disposal (after 21 days)
- Main areas of operation: North Sea, Baltic and Norwegian Sea

Technical Requirement

- Built to commercial standards

MEP Requirement

- compare with national policy
- compliance with ship/shore interface

BWB
SG III 3

GE Navy Position
on Thermal Waste Treatment 10/97

5

3. Evaluation

Operational
- Operational freedom in political terms
- Operational freedom in military terms

Technical
- Cruise ship approach (integrated waste handling & treatment concept with incinerator)
- Storage concept with respect to ship/shore interface

Environmental
- Consideration of 30 years lifetime and development of environmental legislation (international and national)

4. Economic approach

LCC study (30 years) on three variants:

- Solid Waste Storage (cooled storage rooms) and disposal ashore
- Incineration (Cruise ship approach)
- Storage for limited time (7 days) in sensitive areas and incineration

Results

- Today storage and offloading ashore is slightly more expensive than incineration
- Storage concept is feasible on new design ships

5. Decision: Incineration, but ...

- First choice under *operational, technical and economic* aspects: Incineration

- Under *environmental and political* aspects an additional requirement was set by MoD:

  "compliance with Technical Regulation Air (TA- Luft) has to be pursued"

  (TA - Luft regulates gaseous emissions of landbased facilities in GE)

Incinerator Emissions

- emissions measured by industry : "Olau Britannia" (1992)
- emissions measured by BWB : Reconnaissance vessels (1994)

-> Limits acc. to TA-Luft were not exceeded

-> Additional requirement "pursue TA-Luft" seemed to be achievable by aplication of the "GiGo - principle" (Garbage in - Garbage out)

-> Burn only wastes that will not produce harmful (gaseous) emissions

-> Incineration with limited storage capacity

6. Offers by industry

- Incinerator became part of the specification put out for offer
- Industry replied : Effluent Gas Treatment necessary due to anticipated dust emissions
- No detailed information on dust emissions available

-> No incineration, full storage concept

BWB
SG III 3

GE Navy Position
on Thermal Waste Treatment 10/97

7. Current Policy

- TGSS w/o incinerator : full storage concept
- Incineration only, when necessary
- Incineration not necessary for the operational profile of the GE Navy (future?)

8. Concluding remarks (cont'd)

Extremes of waste processing options:

- **Treatment system for mixed wastes and treatment ("cruise ship approach")**

- **Storage concept with segregated waste streams**

8. Concluding remarks

- **Waste treatment certainly necessary for extended operational profiles**
- **back RAS?**
- **Emissions: today no problem (Marpol Annex VI)**
- **Emissions: future in sensitive areas?**

8. Concluding remarks (cont'd)

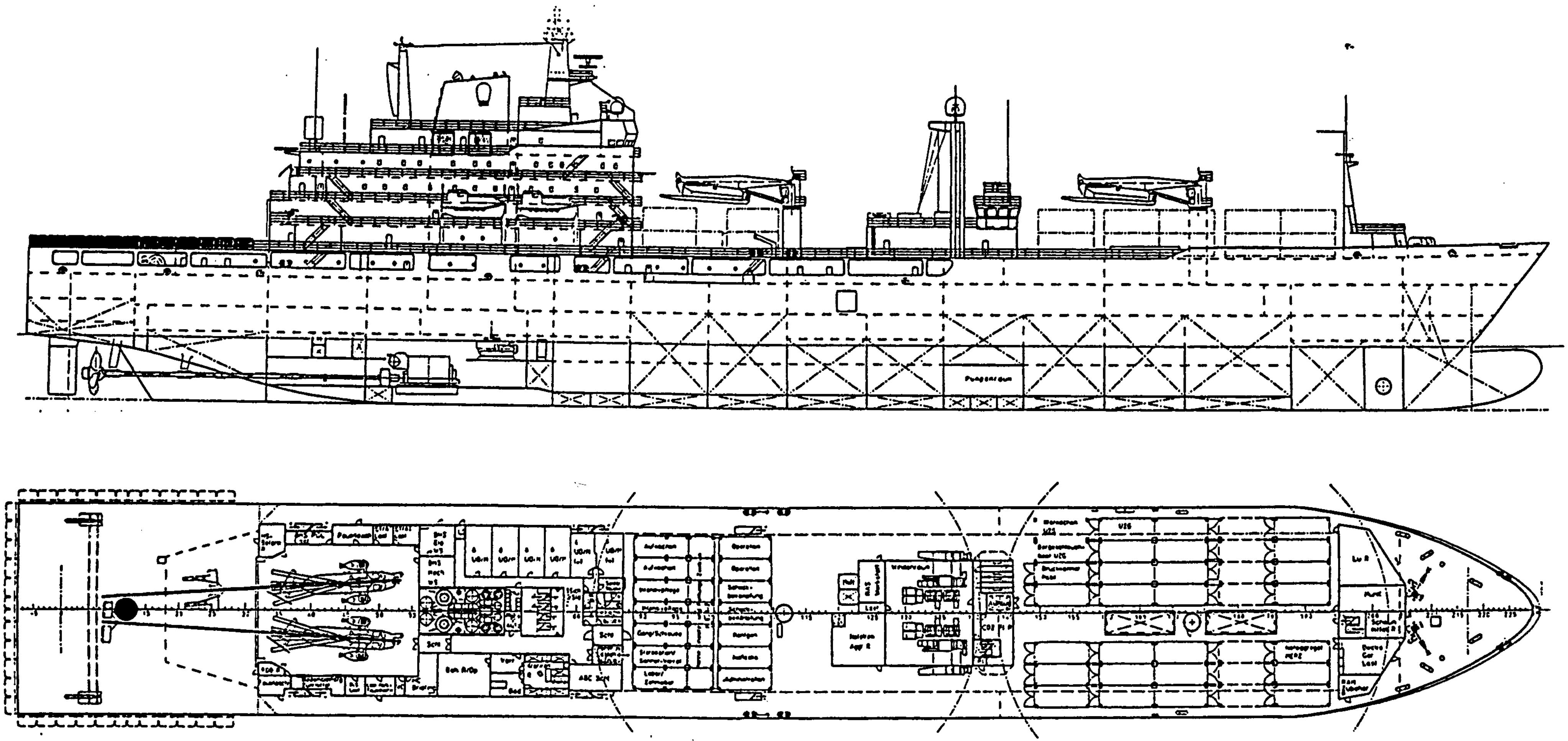
Waste processing & treatment should be integral part of the ship design

-> Systems approach

BWB SG III 3

GE Navy Position on Thermal Waste Treatment 10/97

FEDERAL OFFICE FOR MILITARY TECHNOLOGY AND PROCUREMENT BWB



Task Group Supply Ship
Class 702

Schedule 3

Existing Flue Gas Emissions, future IMO-Regulations and German TA-Air-Regulation

Type of Emission		Measured Emissions on board "Olau Britannia"	Future IMO Regulations	German TA-AIR Regulations
Oxygen	O_2	17,2 %	min. 6 – 12 %	min. 6 %
Carbon monoxide	CO	70,8 mg/m³	200 mg/m³	100 mg/m³
Carbon dioxide	CO_2	59,0 mg/m³	·/.	·/.
Hydrogen chloride	HCl	42,5 mg/m³	·/.	50 mg/m³
Nitrogen oxides	NO_x	191,0 mg/m³	·/.	400 mg/m³
Sulphur oxides	SO_X	·/.	·/.	100 mg/m³
Cadmium	Cd	0,00235 mg/m³	·/.	0,2 mg/m³
Lead	Pb	0,12770 mg/m³	·/.	5,0 mg/m³
Chrome	Cr	0,00155 mg/m³	·/.	
Manganese	Mn	0,01725 mg/m³	·/.	
Copper	Cu	0,02148 mg/m³	·/.	
Soot Number		Bacharach 1	Bacharach 3	Bacharach 1
Unburned components in flue gas		0,65 %	10 %	·/.
Dust		11,0 mg/m³	·/.	30 mg/m³
Flue Gas Temperature in Combustion Chamber		925° C	900 – 1200° C	800 – 1200° C
Unburned Components in ash residues		3,25 %	10 %	·/.

Session 2 - Advanced Incineration Technologies

Chairman: Dr. Kevin Whiting,
Environmental Technology Consultant, United Kingdom

An Overview of Shipboard Solid Waste Disposal – the Past, the Present & the Future?

An Overview of Shipboard Solid Waste Disposal - the Past, the Present & the Future?

Dr Kevin J. Whiting, Independent Consultant, UK

Introduction

As worldwide environmental regulations limit or prohibit the discharge of shipboard wastes into the oceans then commercial shipping and naval operations must identify or develop technologies to manage the waste materials generated on board in ways which do not adversely impact on the environment or, in the case of a naval vessel, the operational status or mission objectives.

Regulatory Situation

The 1973 International Convention for the Prevention of Pollution from ships and its 1978 Marine Pollution Protocol, collectively known as MARPOL 73/78, was one of the earliest efforts to control waste disposal at sea. Annexes I, IV, and V of MARPOL 73/78 cover the disposal of oil, sewage and garbage respectively.

Warships are exempt from MARPOL 73/78, however, US law has extended the Annex V standards to the Navy fleet and the US Congress has directed the Navy to comply with the at-sea solid waste disposal requirements for Special Areas laid down by MARPOL 73/78 (see Table 1). ASpecial Areas@ are designated where environmentally sensitive conditions require stricter controls on disposal. These Special Areas include (or will include) the Baltic Sea, Persian Gulf, the Mediterranean, the Caribbean Seas, the North Sea and the Antarctic Ocean. These Special Areas are situated in regions of critical international importance and deployment of Navy ships in these areas is significant.

Table 1: MARPOL 73/78, Annex V - Waste Disposal Rules

Waste Type	All Vessels Except Offshore Platforms	
	Outside Special Areas	In Special Areas**
Plastics - including synthetic ropes, fishing nets and plastic garbage bags	Disposal prohibited	Disposal prohibited
Dunnage, lining and packing materials	> 25 miles offshore	Disposal prohibited
Paper, rags, glass, metal, bottles, crockery and similar refuse	> 12 miles offshore	Disposal prohibited
Paper, rags, glass, etc. - comminuted or ground*	> 3 miles offshore	Disposal prohibited
Food waste, not comminuted or ground	> 12 miles offshore	> 12 miles offshore
Food waste*	> 3 miles offshore	> 12 miles offshore****
Mixed refuse types	***	***

* Comminuted or ground waste must pass through a mesh size no larger than 25mm
** Special areas are the Mediterranean, Baltic, Red & Black seas, Gulf, N. Sea, Caribbean and Antarctic Ocean
*** For mixed waste, the most stringent disposal or discharge requirements will apply to the mixture
**** For the Caribbean area the regulation is > 3miles offshore

MARPOL non-food waste includes paper and cardboard, metal, glass and plastics. None of these materials may be discharged overboard in Special Areas after the year 2000, and plastics are prohibited from disposal anywhere after 1998. For submarines the date for compliance has been set at 2008.

Past and Current Practice

Commercially available marine incinerators have been evaluated and used in the past and all of these units suffered from the following problems:

batch operation
manual ash removal
excessive weight
high maintenance requirements
excessive temperatures and hot spots creating adverse infrared signatures
inefficient combustion characteristics
potentially hazardous to operatives

The US Navy currently has 107 solid waste incinerators aboard its ships which are located aboard amphibious, auxiliary and carrier class vessels which have high crew complements. The majority of these incinerators are the Vent-O-Matic type, originally designed in the 1950's and suffering from the problems identified above.

Modern systems have been developed, primarily for cruise liners. However, the developers/suppliers are pursuing different objectives with their designs and two such systems are considered here.

Hamworthy Marine, a UK based company, have specifically designed the **Neptune** range of high rate incinerators for shipboard duties. They offer two models the 20R (50 kg/hr) and the 40R (100 kg/hr). The incinerator employs a cyclonic combustion chamber in order to provide a longer solids residence time and the supplier claims the following facilities and benefits:

Compact design (footprint = 4m2, weight = 2800 kg)
Safe operation with interlocks on all doors
Simple operation via local control panel
Low maintenance requirement
Low cost

However, the following disadvantages are evident:

Batch operation
Manual loading of waste
Manual de-ashing
No heat recovery possible

Norsk Hydro Waste Treatment Systems have developed a modular incineration concept for shipboard use on cruise liners. The system is based on a two chamber starved air combustion process with automatic waste feeding and ash discharge facilitating 24 hour/day operation. Modern flue gas cleaning processes are used to comply with IMO regulations. Ash is automatically removed from the incinerator by a vacuum system into one-use bags for storage prior to later delivery to shoreside facilities and ultimate disposal. This is a more complex design requiring a larger footprint and being a heavier piece of equipment. The smallest quoted system can handle 110 kg/hr, weighs 12,800 kg and has a footprint of 7.6m2.

The following advantages are claimed by the supplier:

Pyrolytic operation in first chamber generates less dust
Can also handle food waste
Sludge Oil burner can handle sludge with a water content up to 60%
Automatic ash removal without need to shutdown
Ash contains <5% by weight of unburned carbon
Low maintenance cost

It should be pointed out that this system has been developed as part of a total integrated >green ship= concept capable of disposing of other shipboard waste streams and not just bagged garbage. Direct comparison with the simpler Hamworthy incinerator is therefore not justified.

These two incinerator systems have been described here to demonstrate the large difference between an incinerator designed for a cost effective shipboard incineration duty and a total integrated waste management approach designed specifically for cruise liner applications.

Design Concept

Waste streams generated on board cruise liners and other vessels are very similar to those produced on a Navy vessel, however waste disposal solutions should consider the diversity of ship types and the broad range of mission scenarios. In 1995 the US Navy had approximately 373 ships with crew sizes ranging from 5,000 to 6,000 for an aircraft carrier to 3,000 for amphibious assault ships down to less than 100 for many support vessels, including replenishment, refuelling, repair, minehunting and surveillance ships.

The maximum quantity of garbage generated on an aircraft carrier can be calculated as follows:

crew complement = 6,000
mission time = 60 days
waste generation rate = 1.4 kg/day/person
waste generated = 504 Mg (equivalent to 8.4 Mg/day)

It is extremely important that an integrated waste management solution be developed for Navy applications which would incorporate the currently used landbased systems, ie:

waste minimisation

recycling and re-use
thermal destruction of all solid and concentrated liquid wastes
disposal of ultimate residues

Thermal processing is the necessary solution for the disposal of combustible, non recyclable materials for world Navies. A number of design parameters are critical to successful implementation of any thermal destruction technology on board Navy vessels:

automatic operation, including waste loading and ash discharge
operational cycles, start up, runtime, shutdown, slumber mode
safety and operability
manning requirements, impact on ship operation
mechanical integrity, vibration, noise, corrosion
reliability, availability and maintenance requirements
proven technology at required scale of operation
economics, life cycle costs
warship suitability, ship motion, space constraints, infrared signature

Future Technologies

The US Navy has initiated a research programme to identify and develop >long range options= for the future optimum shipboard waste disposal system or systems. Because naval vessels come in varying sizes it may be that a different strategic approach would be beneficial at either end of the scale spectrum. A number of potential candidates will now be briefly reviewed.

Compact Incinerator

The US Navy=s Office of Naval Research (ONR) and the Department of Defense=s Strategic Environmental Research & Development Program (SERDP) are sponsoring work at the Navy=s Naval Air Warfare Centre, China Lake (NAWCCL) targeted at developing advancements in combustion technology that can be incorporated into the next generation of shipboard incinerators. The development employs acoustic and vortex enhancements to improve the mixing characteristics thereby preventing incomplete combustion or the formation of products of incomplete combustion (PIC=s).

Plasma Arc Systems

Plasma arc pyrolysis is a process that utilises an ultra-high temperature ionised gas stream to completely destroy all organic species, resolving them down to simple gases while simultaneously braking down and fusing inorganic materials to form a vitreous slag. Any heavy metals present are encapsulated within the slag matrix and are rendered non-leachable. Plasma technology was initially developed to destroy intractable wastes such as radioactive and extremely hazardous materials and a number of commercially available plasma processes are available (see Table 2).

Table 2: Commercially Available Plasma Arc Processes

Developer	Country	Process
Retech Inc	USA	Plasma arc torch reactor
Plasma Energy Inc	USA	Plasma arc melting furnace
TSK	Japan	>MEDUSA= Plasma arc furnace
Ebara Infilco	Japan	Plasma arc melting furnace
Europlasma	France	Plasma torch furnace

Source: KJ Whiting & Associates

The US Navy is currently developing a plasma pyrolysis process for shipboard application based on a Retech PACT-1 design. The Plasma Arc Waste Destruction System (PAWDS) conceptual design has been developed as two distinct sub-systems:

1) a plasma eductor to rapidly gasify pulped organic wastes (paper, cardboard and food)
2) a separate plasma arc for inorganic wastes (glass, metals and miscellaneous items)

The advantages of this system over existing incineration technology include:

higher operating temperature and improved temperature control
potentially greater reliability
reduced size and weight
reduced volumes of ultimate residues
greater processing capacity

However, a number of technical problems remain to be solved for shipboard application:

excessive size requirements and difficult to retrofit into existing ships
weight is a critical concern for shipboard systems
unacceptable start up and shutdown times
stringent warship shock and vibration requirements
off gas treatment and infrared signature
molten slag handling at sea poses hazard and safety concerns for operatives

Vitrification

Vitrification is closely related to plasma arc technology. Waste is heated to approximately 1650oC by electric current or the combustion of fossil fuels. Organic materials are destroyed via a thermolysis (pyrolysis) mechanism with the volatile off gases combusted in an afterburner. The inorganic constituents in the waste are melted and removed as a liquid slag. When the melt is cooled, a vitreous solid, non-leachable mass is formed, encapsulating any heavy metals or other environmentally adverse contaminants.

This technology is well advanced in landbased applications and a number of commercial systems are available (see Table 3).

Table 3: Commercially Available Vitrification Technologies

Developer	Country	Process
TSK	Japan	Vortex melting furnace (fossil fuel fired)
NKK/Tanabe	Japan	Slag resistance melting furnace
Kubota/Takuma	Japan	Surface melting furnace
ABB Japan	Japan	>DEGLOR= electric melting furnace
Steinmhller/MAN	Germany	'FOSMELT' - fossil fuel fired melting furnace 'ELOMELT' - electric arc melting furnace
Lurgi/Sorg	Germany	>SOLUR= - electric melting furnace
VERT	UK	McNeill molten glass furnace (fossil fuel fired)

Source: KJ Whiting & Associates

Molten Metal/Molten Salt

Molten Metal Technology, otherwise known as **Catalytic Extraction Processing (CEP)**, was developed by Molten Metal Inc. of the USA. Based on technology developed in the steel industry, the CEP reactor is a refractory-lined vessel which is equipped with an induction furnace for heat input during start-up. Solid wastes are fed into the reactor via a top hopper system.

The CEP reactor utilises a metal bath, usually iron or nickel, operated at temperatures above its melting point. The liquid metal acts both as a homogenous catalyst and as a solvent. The solid residues undergo two processes in the metal bath:

Catalytic dissociation and dissolution: the catalytic effect of the molten metal causes complex compounds in the feed to be dissociated into their constituent elements, which readily dissolve in the liquid metal forming elemental intermediates;

Product synthesis: the addition of select co-reactants (eg., oxygen, lime, etc.), or by controlling operating conditions (eg., pressure and temperature), the dissolved elemental intermediates can be reacted to form desired products with commercial values. Thermodynamic equilibria constraints determine which products will be formed, while solution equilibria constraints determine how the mix of products will be split among various products eg., metallic, ceramic and gases.

Oxidation with air can be carried out in molten sodium carbonate above 900oC. Acidic products react to form salts which dissolve in the molten bath. **Molten Salt Oxidation** can be applied to combustible solids, organic liquids, solutions and slurries. The gaseous products may contain unoxidised waste that has passed through the bath and an afterburner may be needed. The technology has been applied on a small scale for more than 40 years for the destruction of military waste materials. The destruction of ship derived solid wastes by this technology is currently under investigation by the Naval Surface Warfare Center.

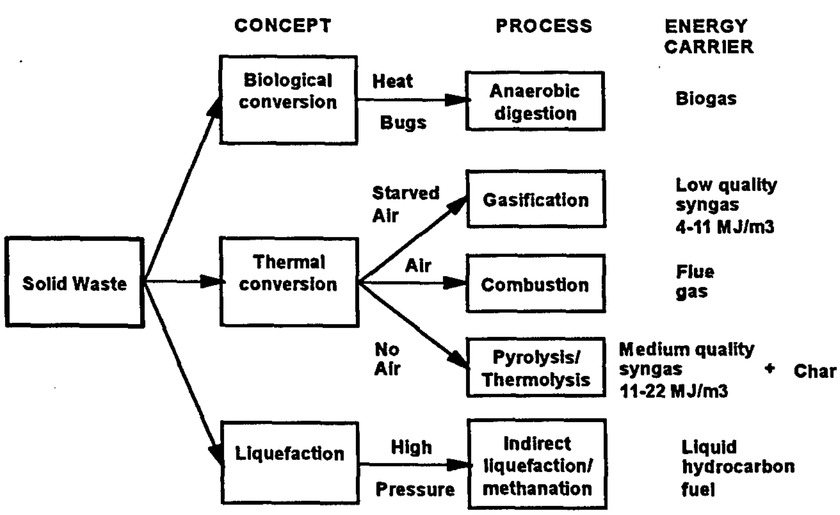
Supercritical Water Oxidation

Water above its critical point, ie. above 374oC and a pressure of 220 atmospheres, behaves like a gas rather than a liquid and is miscible with other gases, but not salts. Under supercritical conditions organic compounds and oxygen are both soluble in the water and can react readily. Exposure time within the reactor is less than 2 minutes for >99% conversion. Optimisation of temperature and reactant concentrations can reduce the required residence time and lead to a smaller reactor.

The **Supercritical Water Oxidation (SCWO)** process would entrain shredded waste in water (1-20% concentration) which would be pressurised and preheated and introduced into the reaction chamber for exposure to an oxidant (air, oxygen or hydrogen peroxide). The temperature-time history is closely controlled and organic waste is converted to CO_2 and water. Any sulphur, chlorine and phosphorus are converted to the relevant acid which is neutralised within the process by the injection of sodium hydroxide.

The technology has been demonstrated at pilot scale to destroy a large number of organic compounds but as yet no trials have been conducted to determine the performance of the process with shipboard type wastes.

Thermolysis/Gasification

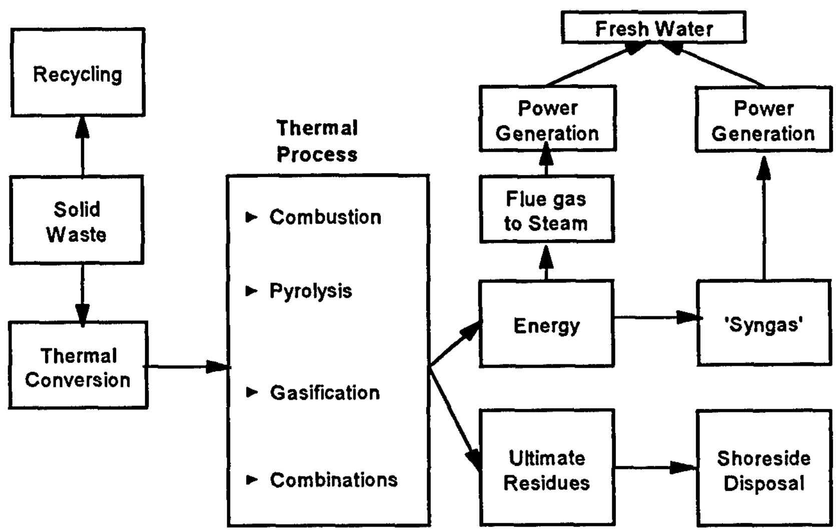


The options currently considered for the landbased thermal conversion of solid

waste are shown in Figure 1.
Figure 1: Thermal Conversion Options for Solid Waste

Thermolysis (Pyrolysis) and Gasification offer potentially attractive methods of waste disposal as well as an opportunity to convert non-recyclable waste materials into useful products, eg. energy (see Figure 2). These processes can be applied in two main ways:

The use of thermolysis or gasification to produce a >syngas= which is combusted to provide hot flue gases from which steam and then electricity are generated



The use of thermolysis or gasification to produce a >syngas= which is cooled and cleaned prior to the direct generation of electricity via gas engines
Figure 2: Process Options for Shipboard Thermal Treatment

Thermolysis (Pyrolysis) is the thermal degradation of carbonaceous materials at temperatures between 400 and 800oC either in the complete absence of oxygen, or with such a limited supply that gasification does not occur to any appreciable extent. The products of pyrolysis always include gas, liquid and solid char with the relative proportions of each depending on the method of pyrolysis and the reaction parameters.

Slow pyrolysis (carbonisation) requires a slow reaction at low temperatures to maximise the yield of solid char
Fast or flash pyrolysis is used to maximise either gas or liquid products. The gas is of a medium heating value (13-21 MJ/Nm3) and the liquids, often referred to as >oil= are very complex mixtures of hydrocarbons. The reaction can be controlled to maximise the production of gaseous products

In a conventional **Gasification** process, the majority of the carbon is converted into the gaseous form, leaving an inert residue, by partial combustion of a portion of the fuel in the reactor with air, or with pure oxygen, or with oxygen enriched air or by countercurrent reaction with steam. Relatively high temperatures are employed, 900-1100oC with air and 1000-1400oC with oxygen. Air gasification is the most widely used technology forming a low heating value gas, containing up to 60% nitrogen, with a heating value of 4-6 MJ/Nm3. Oxygen gasification gives a better quality gas of 10-18 MJ/Nm3 but, of course, requires an oxygen supply with the associated issues related to cost and safety.

For shipboard application of a gasification process, a small scale technology should be evaluated. One such technology is the process being developed by WGT , a UK based company, which aims to achieve three main objectives:

conversion of the solid waste materials into syngas
to maximise the yield of syngas
to maximise the calorific value of the syngas

The solid waste is pre-treated to remove recyclable materials, eg. glass and metals, which would occupy unnecessary reactor volume, and is purged with an inert gas, such as carbon dioxide or nitrogen, in order to remove the entrained air prior to feeding into the reactor which is a slowly rotating, externally heated cylinder. The process operates at a temperature between 700 and 900oC, in an oxygen deficient environment which causes the waste to gasify and 'crack' into smaller (lower molecular weight) gas molecules. Any solid carbon or ash produced during the reaction is transported out of the reactor by the rotation.

The produced syngas and solid char are separated and the syngas passes through a hot cyclone to remove entrained particulates. It is then quenched to ambient temperature by direct injection of water and further cleaned by conventional scrubbing processes to remove acid gases. The syngas is then directly combusted in a gas engine for power generation.

For a garbage-like material, the CV of the syngas would be about 27MJ/Nm3 (cf. 36 MJ/Nm3 for natural gas) which would generate electrical power in the order of 600 kWh/tonne of waste.

WGT have operated a pilot plant since 1993 with a throughput capability of 60 kg/hr and an in-line gas engine rated at 55kW. The pilot plant has been demonstrated over many hours and processed a large number of different waste materials. The process has been shown to possess the following attributes:

simple to operate and control
rapid start up and shutdown characteristics
small, compact, modular design
large turndown capability

Microwave Pyrolysis

The technology utilises microwave power to heat material in a slowly revolving enclosed pyrolysis chamber without the presence of oxygen. The chamber also contains a microwave receptive powder which, as well as having strong chemical reducing properties at elevated temperatures, gently envelopes the material being treated, ensuring even non-microwave receptive materials are raised to the required temperatures in the strong reducing environment.

The temperature of the powder and all of the materials can be precisely controlled, maintained at plateau temperatures, or raised as high as 1500oC with the material exposed to these temperatures for long residence times, if required. The stable conditions established ensures the waste is converted into harmless fractions, typically a hydrocarbon gas, liquid hydrocarbons, carbon char and ash. The released vapours are contained within the process allowing the opportunity for re-treatment if necessary. Once the required temperature/time profile has been established for a particular waste material, then the conditions to achieve satisfactory destructive distillation can be exactly maintained via a reproducible protocol.

Fluidised Bed Systems

Fluidised bed combustion systems have been used to convert a variety of waste materials (fuels) into energy for many years. Systems have been used extensively in Scandinavia for biomass fuels, such as wood wastes, bark and peat, and also in developing countries for such diverse materials as coconut husks, rice hulls and cherry and olive stones. In Japan, the fluidised bed has been applied extensively for the disposal of pre-sorted garbage, with more than 100 commercial facilities in operation.

Fluidisation is the term applied to the process whereby a fixed bed of fine solids is transformed into a liquid-like state by contacting with an upward flowing gas. Sand usually acts as the thermal medium and as a consequence of the very large surface area provided by the sand particles, the fluidised bed acts as an enormous heat sink . Heat transfer rates are very high and garbage which is fed to the top of the bed is rapidly dried, heated and ignited.

There are three main types of fluidised bed:

Bubbling
Circulating
Revolving

In the classical **"Bubbling" fluidised bed (BFB)** the bed solids are large enough (approx. 750-1000 :m) and the gas velocity low enough (1-3 m/s) to ensure that all the particles, constituting the bed, are not entrained and carried out by the fluidising gas. Thus the bed operates below the minimum terminal velocity of the smallest particle in the bed. The phenomenon of "bubbling" occurs at fluidising velocities above the minimum, with the excess gas above the minimum fluidising requirement, forming bubbles. These bubbles of gas can be seen to coalesce and grow as they rise rapidly through the bed. A BFB resembles a violently boiling liquid. The presence of bubbles in the bed promotes intense circulation and mixing of the solids, leading to isothermal conditions throughout the bed. Depending on the design, heat transfer is effected by means of a combination of in-bed heat transfer, radiant heat transfer in the freeboard

As the fluidising velocity to a BFB is slowly increased the bubble phase will disappear leading to a condition of uniformity, referred to as the turbulent state. If the gas velocity exceeds the transport velocity of the particles then, in the absence of solids recycle, the column containing the particles, would empty rapidly.

However, if the solids ejected from the bed are captured in a cyclone and returned via a standpipe to the bottom of the bed then it is possible to maintain a relatively large solids concentration in the column. This situation is referred to as a **"Circulating" fluidised bed (CFB)**. CFB combustors utilise smaller particles (approx. 250 :m) and higher gas velocities (5-6 m/s).

The **ARevolving@** or **ATwin Interchanging@ Fluidised Bed (TIF)** was developed by the Ebara Corporation of Japan to improve the operational and combustion characteristics of the conventional BFB and to offer a system not requiring the operational complexities of the CFB. In essence the furnace is designed to effect greater movement, and hence turbulence, in the dense phase fluidised bed.

An inclined distributor plate with a number of separate fluidising air supply chambers to provide differential air flows across the bed. In addition to promoting rapid and turbulent mixing of waste and bed material through the revolving action, heavy inert non-combustibles migrate to the sides of the bed for removal. An angled furnace wall configuration immediately above the fluidised bed zone encourages the revolving action, restrains bed expansion and minimises bed carry-over. The controlled elliptical circulation patterns converge in the centre of the bed ensuring effective vertical and lateral mixing which in turn produces a high combustion efficiency.

The majority of fluidised beds installed in Japan are the Revolving type (34%) and the smallest installed unit has a capacity of 1500 kg/hr and operates for 16 hours/day.

A recent development has been reported by Sheffield University (UK), the **ARotating@ Fluidised Bed (RFB)**. The RFB comprises a cylindrical bucket rotating around its axis of symmetry. Sand granules are introduced into the cylinder and the particles are forced to the wall by the centrifugal force. The wall serves as the gas distributor and fluidising gas is injected through the porous wall. The particles fluidise when the bed pressure drop is equal to the effective weight of the particles in the centrifugal field. The minimum fluidising velocity can be achieved for any gas flowrate by changing the rotating speed of the bed which allows the RFB incinerator to accommodate different types of waste and different throughputs by adjusting the rotational speed of the bed.

This system is still at the early stages of development.

Electrical Heating Systems

There are three main systems under development:

Electric Pyrolyzer - IWT system from Advanced Waste Treatment Technology Inc.
Electric Pyrolyzer - Westinghouse Electric Corporation
Advanced Electric Reactor - J.M. Huber Corporation

These systems all subject the waste to pyrolytic destruction conditions with the heat supplied by electric heating elements. The author is unaware that any of these systems have been evaluated for shipboard application.

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<u>Session 2</u> - Advanced Incineration Technologies

Adaptation of Waste Management Systems by the International Navies

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ADAPTION OF WASTE MANAGEMENT SYSTEMS BY THE INTERNATIONAL NAVIES

Lecture given by Jochen Deerberg
on the occasion of the

US - EUROPEAN WORKSHOP

October 29, Brussels, Belgium

1) INTRODUCTION

I am very glad to have the possibility today, to show and explain you the state-of-the-art in Waste Management Technology on board passenger vessels. The highest possible environmental protection is the biggest future challenge in the industry. I have not to repeat the impressive figures of the growth of the passenger shipping industry and the forecast. I expect a Newbuilding order income until 2002 of 40 Vessels only in the Cruise Industry, not to mention the Ferry and Fastferry sector.

I will give you later on an overview of the new IMO draft protocol 1997 effecting the shipping and shipbuilding industry.

To comply with these rules, a reliable Waste Treatment System is needed. The Deerberg Multi Purpose Waste Management System can already fulfil today the stringent future rules and regulations. DEERBERG-SYSTEMS IS THE *FORERUNNER IN PHILOSOPHY.*

The modern Cruise Ship is a floating town with thousands of passengers and crew on board. It has similar environmental challenges as any small city located in the middle of an ecologically sensitive area.

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Among others, the biggest challenge within the Cruise Industry is first to understand the complicated array of international requirements and to manage the operation in compliance with these rules.

The orders placed in the last years show the direction for future dimensions of new **MEGA-CRUISERS (over 100.000 + dwt)** and the demand for new solutions.

One of the first vessels of this MEGA-SIZE, the Princess Cruises „Grand Princess“ will be equipped with a trendsetting Multi Purpose Waste Management Systems, developed by D-S.

2) Problem definition

Effective environmental management of Cruise Vessels requires a combination of sound environmental policies, on board practices and waste handling equipment.

On board a Cruise Vessel a huge amount of waste is generated, which has to be treated properly without harming the health and warefare of the persons involved.

2.1) SAMPLE:

Grand Princess, 4.400 Persons on board
Owner: Princess Cruises, Yard: Fincantieri

Burnable Waste:	1,5 kg/day/person	=	**6.600 kg/day**
Glass:	0,7 kg/day/person	=	**3.080 kg/day**
Tins:	0,02 kg/day/person	=	**90 kg/day**
Food+Wet Waste:	1,4 kg/day/person	=	**6.130 kg/day**
	3,62 kg/day/person	=	**15.900 kg/day**

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3) DETERMINATIVE FACTORS FOR A WASTE MANAGEMENT SYSTEM

The determinative factors designing a Waste Management System which can handle the entire amount of garbage in a proper and suitable way are as follows:

CRUISING AREA

Most of the vessels are designed for world-wide cruises, apart of the well known cruising areas new venues will be developed.
Not in any case you will find sufficient waste receiving stations or port facilities.

INCREASING ZERO DISCHARGE

As per today MARPOL allows the disposal of certain solid wastes into the ocean.
But for sure this has a negative impact to the environment.
Already nowadays most of the Cruise Operators adapted this fact into their environmental policy and are following the strict zero discharge of solid waste.

LEGISLATION AND REQUIREMENTS

As already mentioned at the beginning there are many of international, national and local rules to follow, plus the anticipation of the new IMO DRAFT PROTOCOL of 1997.

ONSHORE REGULATION / RECYCLING

A Waste Management System should offer the operator the highest flexibility and a number of operational options.

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This includes not only the treatment of the entire waste amount on board, but as well the treatment of waste, finally for disposal to shore for dumping and recycling.

HUMAN FACTOR

Even with all technology available we have to realise, that the on board personnel has to handle the waste.
Although the treatment processes run automatically, there remains the manual transport, in case the operator decides so, the manual sorting and the manual feeding into the automatic processing lines.

At the end we have to see, that the contact with waste is reduced to the minimum of hygienical and health risk.

4) *MULTI PURPOSE WASTE MANAGEMENT SYSTEM*

Within the last years Deerberg-Systems introduced the

MULTI PURPOSE WASTE MANAGEMENT SYSTEM

to the shipping and shipbuilding industry. Therefore I will not go to deep into technical details.

A Waste Management System designed according the above mentioned factors could be as follows:

BURNABLE WASTE

Shredding, storing and automatic feeding into the Incinerator.
Automatic de-ashing for discharge to sea or landing on shore .

It is important that the material given to shore will comply with on shore rules. This has already been indicated in the determinative factors.

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Several time we have tested the ash residuals from the Incinerator. The tests have been done according the EPA TC **(Environmental Protection Agency Toxical Characteristics)**. According to this list, 30 different components and their values where checked and identified.

Result: ***The ash has been classified as so called non-hazardous, which allows an easy disposal to shore, worldwide!***

FOOD AND WET WASTE

Food and Wet Waste is one of the most critical components in the waste fraction, especially with a look on hygienic aspects.
In deviation from all other waste components, Food and Wet Waste will be treated at the spot of origin **(galley, preparation, pantry and restaurant).**
This is especially to follow the USPH guidelines avoiding cross contamination and a manual transport through the ship.

Food and Wet Waste is macerated to a slurry by the Pulper and is pumped through a piping system into the waste room where the Waterpress is located. The latest installations of the Deerberg MPWMS are equipped with our new development - the EWP 2700 & EWP 2701 - a Waterpress which can handle 8-10 Pulpers parallel with a capacity of 4.000 kg Food Waste per hour.
The Waterpress divides the solids from the liquids. The solids will be pumped into the food waste holding tank for later, automatic incineration, the liquids are pumped back to the Pulper station, because they are just used as a transportation medium.

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GLASS, TINS & ALUMINIUM

In case you are operating in an area where receivers forward the landed glass and tins to a recycling facility or a landfill, it is common practise to separate the glass and the tins from the other waste.

For volume reduction and easier storage on board, glass is shredded or crushed.
Tins & Aluminium are fed into the densifier, where they are compacted to blocks.

Due to remaining liquids within the treated waste, it must be stored on board in cooling rooms to avoid increasing smell and growth of bacteria.

Having no possibility for the shore disposal, you can optionally pass glass and tins as well through the incinerator.

WITH THIS TECHNOLOGY, DEERBERG IS THE *FORERUNNER IN TECHNOLOGY*, AS THIS IS THE ONLY INCINERATOR ON THE MARKET, WHICH CAN HANDLE GLASS AND TINS.

The advantages are obviously:

- **No sorting needed (human factor)**
- **Glass and Tins are disinfected in the incinerator (but will not burn - Recycling)**
- **Storage on board does not require cooling rooms (No waste of precious space)**
- **In case of an emergency discharge overboard you can be sure that:**

  you will not unintentionally discharge plastic with the glass and tins

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SEWAGE

The sewage will be treated in Biological Treatment Plants which produce the natural process to break down black water to environmentally harmless components.

SLUDGE OIL

After the separation process from water, sludge is burnt in the Incinerator.

GREY WATER

There is a waste fraction, not yet regulated under IMO rules, but is already nowadays a headache for the operators -
so called **GREY WATER**.
On big Cruise Vessels up to 1.500 tons per day of Grey Water is generated. It comes from galley operation, dishwashers, laundry, pools and showers.

When discharging this water, it forms a grey cloud in the unspoiled water and will immediately attract the passengers attention.
There are different technologies which we are working on, to eliminate the harmful substances and colour.

....but the millions of dollars spent on the latest Waste Management Systems and Garbage Disposal Equipment - such as Shredders, Incinerators and Pulpers - would be meaningless without integrating the

WASTE MANAGEMENT SYSTEM

into the operators

TOTAL QUALITY MANAGEMENT...

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5) TOTAL QUALITY MANAGEMENT

TOTAL QUALITY MANAGEMENT with regard to WASTE MANAGEMENT means the definition of a *corporate environmental policy.*

This policy

- **is valid for the entire fleet**
- **guarantees cost effective operation**
- **produces optimal results**
- **assists the operator in its marketing effort of a „GREEN SHIP“**

5.1) MAIN ACTIVITIES

The main activities which result in a corporate environmental policy are as follows:

Documentation

- Definition of status quo, meaning analysing any waste and its production, place and amount
- Ongoing records for success / failure control
- Handbooks and guidelines how to treat the waste, how to operate the equipment
- Maintenance of all the procedures and the Waste Handling itself

Waste minimisation / Substitution of materials (e.g.)

- Washable heavy duty plastic drink containers instead of lightweight plastic cups
- Paper instead of Styrofoam coffee cups
- China instead of plastic plates in the buffet lines
- Paper instead of plastic laundry bags **..........and so on**

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Training

A key component of any environmental program is education. The crew and staff has to undergo comprehensive training to ensure their understanding of the environmental policy. **Especially when the crew is changing very often.**

But training is not enough, however. Accountability is the key and strict disciplinary procedures apply to any violation.
Once the directives and training has been made, periodically and systematically internal audits have to be made to assure compliance with the policy.

As with any human managed system, nothing remains static. Rules and regulations change, technology evolves, equipment fails and definition of acceptable practices change also.

The TQM system must therefore be able to accommodate changes as well.

Marketing

Inform the passengers about the fleets environmental policy.
It has been noted that most passengers are very familiar with environmental friendly procedures, because they practise it at home. They want to participate in keeping the ship and especially the oceans clean.

Communications with external interfaces like ports or waste receivers are important.

Communications with environmental watchdogs like Center for Marine Conservation or green groups are essential.

At least all those information to third parties will assist the operator in his marketing tool for the „GREEN SHIP“.

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6) QUINTESSENCE

For assurance of environmental compliance the use of TQM for sure is a valuable management tool.
This tool, combined with a state-of-the-art MPWMS can really result in a „GREEN SHIP".

Deerberg-Systems´ target is not only to be a partner for the shipping and shipbuilding industry with regard to Waste Management, but can also assist the operator within the different steps to reach a corporate environmental policy, especially with regard to training and documentation.

DEERBERG-SYSTEMS YOUR RELIABLE PARTNER.

DEERBERG-SYSTEMS

J. Deerberg

JOCHEN DEERBERG
OWNER & CEO

Deerberg-Systems · Moltkestraße 6a · D-26122 Oldenburg
Telefon +49-(0)441-776062 · Telefax +49-(0)441-777337

Deerberg Activities

DEERBERG LÜBBECKE

1756 **Founded as Blacksmith's shop**

19. Century Locksmith's shop

1930-97 Extension to a leading middle sized department store company. 6 Family-Stores.

1935 Oil- and Fuel-Trading

1948 Deerberg-Electronics

1949 Deerberg-Hotel

until 1951 Deerberg production and sales of machinery for agriculture

Activities Jochen Deerberg

1979 Deerberg-Consultancy

1982 Deerberg-Systems Waste-Management onboard ships

1985 **DEERBERG-TRADING** Interior Outfitting Equipment for Cruise Vessels & General Trading

1997 **DEERBERG-SYSTEMS Leading Supplier for Waste Management Systems onboard 89 Cruise Vessels and 700 other ships.**

Basis for the whole Deerberg development was quality in tradition and customer service. This background was always the main guideline for Jochen Deerberg - activities.

QUALITY IN TRADITION SINCE 240 YEARS

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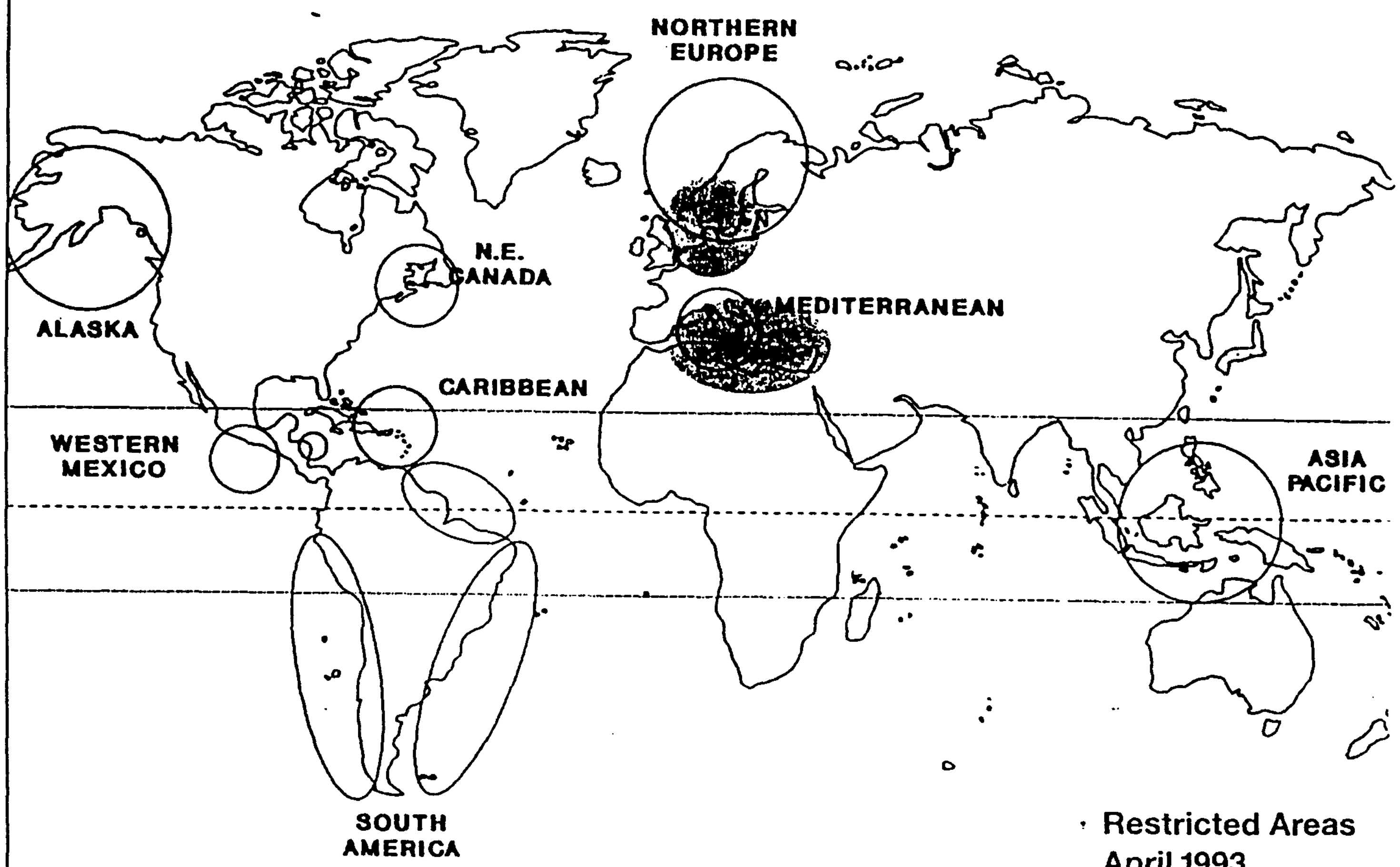
DEERBERG SYSTEMS

SELECTED WORLD VENUES



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DETERMINATIVE FACTORS

FOR A

MULTI PURPOSE WASTE MANAGEMENT SYSTEM

- CRUISING AREA (WORLDWIDE)
- INCREASING „ZERO DISCHARGE“
- GLOBAL LEGISLATIONS (IMO)
- SPECIAL LOCAL REQUIREMENTS
- FUTURE REQUIREMENTS
- ONSHORE RECYCLING OPTION
- HUMAN FACTOR
- FULFILLMENT OF ONSHORE REGULATIONS

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DEERBERG SYSTEMS

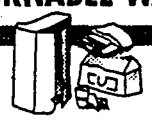
CALCULATION OF WASTE AMOUNT

-NON-SORTING SOLUTION-

Cruise Liner with 4.400 Persons on Board

100%

BURNABLE WASTE



6.600 kg/day
64 cbm/day

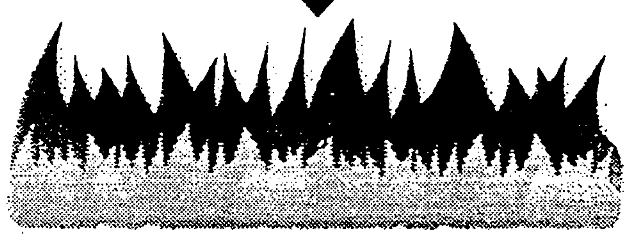
FOOD WASTE

6.130 kg/day
14 cbm/day

GLASS AND TINS

3.170 kg/day
12 cbm/day

Gross Weight: 15.900 kg/day
Gross Volume: 90 cbm/day



Multi Purpose
Waste Management System

Burnable Waste:	**230 kg = 1,7 cbm**
Food Waste:	**60 kg = 0,4 cbm**
Glass & Tins:	**3.170 kg = 2,4 cbm**
Σ:	**3.360 kg ≈ 4,5 cbm**

≈4-5%

≈ 4-5 Containers/day

DEERBERG SYSTEMS

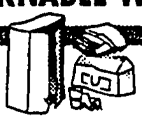
CALCULATION OF WASTE AMOUNT

-SORTING SOLUTION-

Cruise Liner with 4.400 Persons on Board

100%

BURNABLE WASTE



6.600 kg/day
64 cbm/day

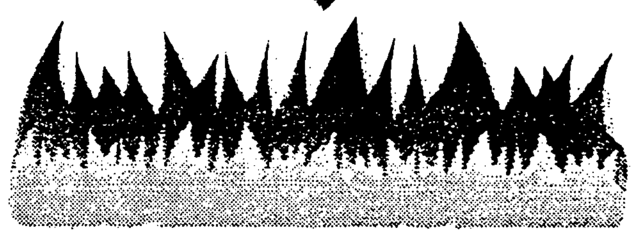
FOOD WASTE

6.130 kg/day
14 cbm/day

GLASS AND TINS

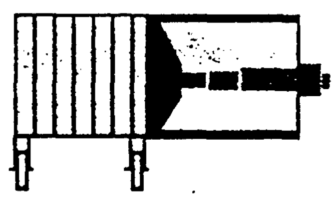
3.170 kg/day
12 cbm/day

Gross Weight: 12.730 kg/day
Gross Volume: 78 cbm/day



Multi Purpose Waste Management System

Burnable Waste:	**230 kg = 1,7 cbm**
Food Waste:	**60 kg = 0,4 cbm**
Σ:	**290 kg ≈ 2,1 cbm**



Glass Crusher Tin Compactor

Glass & Tins:
3.170 kg = 2,4 cbm

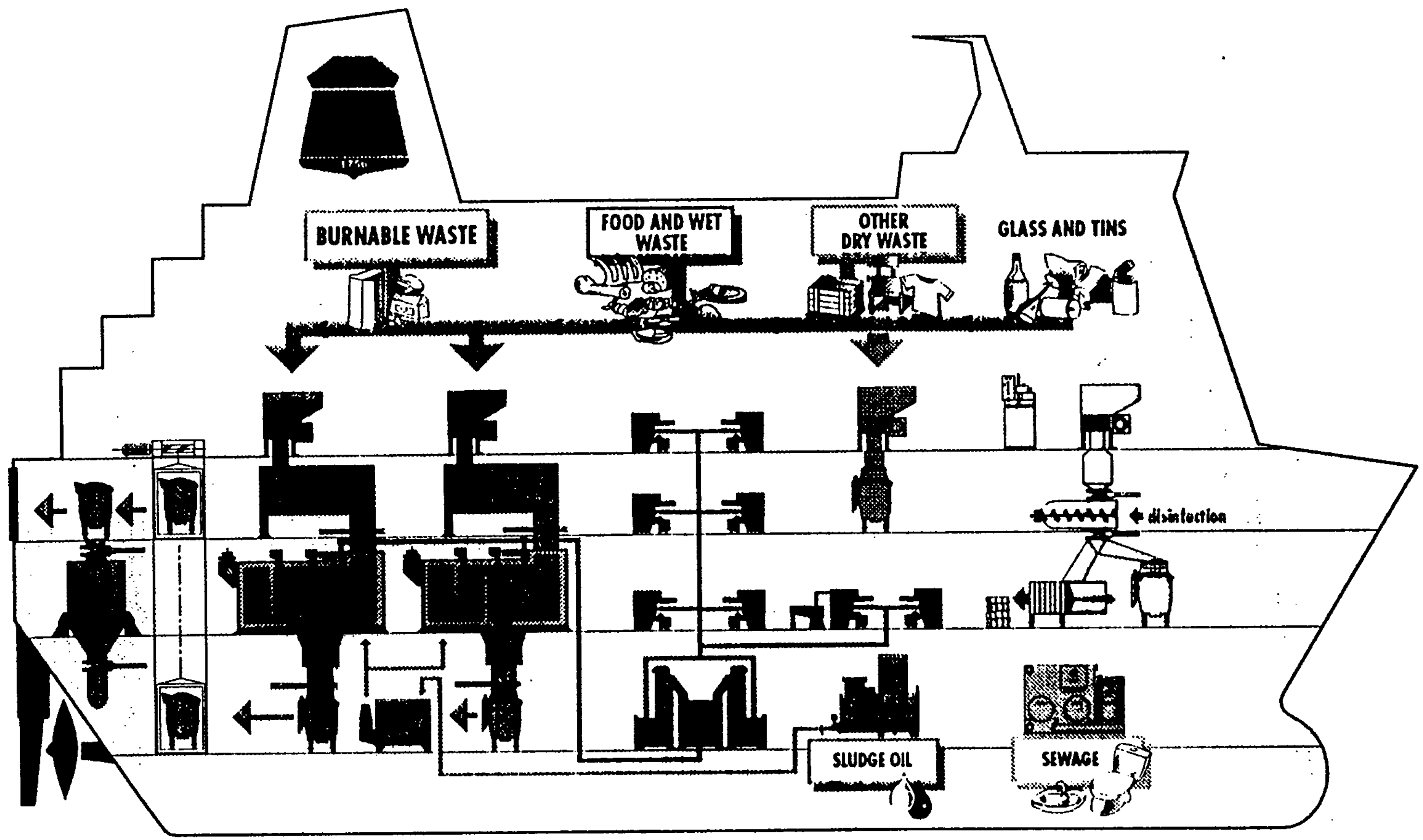
ONSHORE

≈4-5%

≈ 2-3 Containers/day

≈ 2-3 Containers/day

SORTING OR NON-SORTING SOLUTIONS



ADVANTAGES:
- **DISINFECTED AND NOT SMELLING**
- **WORLDWIDE ONSHORE LANDING OF ASH RESIDUALS**

EMISSION CONDITIONS

LAND & AIR

EPA IMO

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TOXITY CHARACTERISTICS OF EPA
TC Constituents and Regulatory Levels

Type of Emission	Regulatory Levels (mg/ltr.)	Actual Test Result NORDIC EMPRESS [1] (mg/ltr.)
Arsenic	5,00	BDL [2]
Barium	100,00	BDL
Benzene	0,50	0,29
Cadmium	1,00	0,02
Carbon tetracloride	0,50	BDL
Chlordane	0,03	BDL
Chlorobenzene	100,00	BDL
Chloroform	6,00	BDL
Chromium	5,00	BDL
Cresol	200,00	4,05
1,4 Dichlorobenzene	75,00	BDL
Dichloroethane	0,50	BDL
1,1 Dichloroethylene	0,70	BDL
2,4 Dinitrotoluene	0,13	BDL
Endrin	0,02	BDL
Hexachloroethane	3,00	BDL
Lead	5,00	BDL
Mercury	0,20	BDL
Methoxychlor	10,00	BDL
Methylethylketone	200,00	BDL
Nitrobenzene	2,00	BDL
Pentachlorophenol	100,00	BDL
Pyridine	5,00	BDL
Selenium	1,00	BDL
Silver	5,00	BDL
Toxaphene	0,50	BDL
2,4,5 Triclorophenol	400,00	BDL
2,4,6 Triclorophenol	2,00	BDL
2,4,5 TP (Silvex)	1,00	BDL
Vinylchloride	0,20	BDL

[1] DEERBERG-SYSTEMS/SEEBECK TECHNO PRODUKT
Waste Management on Board RCCL's NORDIC EMPRESS
[2] Below Detectable Levels

Examination was carried out by ENVIROPAC INC.
Miami Division 4790 N.W. 157th Street Miami, Fl 33014-6421

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DEERBERG SYSTEMS

EXISTING FLUE GAS EMISSIONS AND FUTURE IMO-RGULATIONS*

DEERBERG INCINERATOR RESULTS

Type of Emission		Olau Britannia	Fascination	RCI Green Ship Concept	Navy Standard	Futur IMO Regulations	Deerberg fulfills
Measured in year:	⇒	1991	29.06.1994	1995		Year 2000	today
Oxygen	O_2	17.2 %	10,9 %	11 %		6 - 12 %	√
Carbon monoxide	CO	70,8 mg / m³	60,9 mg / m³	200 mg / m³		200 mg / m³	√
Carbon dioxide	CO_2	59.0 mg / m³	2.5 Vol. %	5 Vol. %		./.	√
Hydrogen cloride	HCI	42,5 mg / m³	24,5 mg / m³	./.		./.	√
Nitrogen oxides	NO_X	191.0 mg / m³	30,4 mg / m³	180 mg / m³		./.	√
Sulphur oxides	SO_X	./.	./.	120 mg / m³		./.	√
Cadmium	Cd	0.00235 mg / m³	< 0.1 mg / m³	./.		./.	√
Lead	Pb	0.1277 mg / m³	< 0.5 mg / m³	./.		./.	√
Chrome	Cr	0.00155 mg / m³	< 0.1 mg / m³	./.		./.	√
Manganese	Mn	0.01725 mg / m³	./.	./.		./.	√
Copper	Cu	0.02148 mg / m³	./.	./.		./.	√
Soot Number		Bacharach 1	Bacharach 1	./.		Bacharach 3 or Ringelmann 1	√
Unburned components in flue gas		0.65 %	./.	./.		./.	√
Dust		11.0 mg / m³	./.	250 mg / Nm³		./.	√
Flue gas temperature in combustion chamber		925 °C	890 °C	./.		850 °C - 1200 °C	√
Unburned components in ash Residues		3,25 %	0,9 %	./.		10 %	√
Flue gas Temperature		350 °C	350 °C	./.		350 °C	√

* Draft Protocol of 1997 to amend the International Convention for the prevention of Pollution from Ships. 1973. as modified by the Protocol of 1978.

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GREYWATER

- **BIG HEADACHE**
- **SOLUTIONS IN PROCESS**

TARGET:

ELIMINATION OF HARMFUL SUBSTANCES, COLOUR AND ORGANICAL LOADS OF THE GREYWATER

e.g. BOD_5 = 15.000 mg O_2/ l IN PULPER WATER

COMPARISON: MAXIMUM OUTLET FROM SEWAGE TREATMENT PLANT = 50 mg O_2 / l

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DEERBERG SYSTEMS

Preventative Waste Management

- View everything as a potential source of waste
- Start at the planning stage to eliminate non- environmentally friendly material
- Incorporate your vendors
- SUPPLIERS CAN BE PARTNERS

Sample for plastic substitution:

Plastic item	Replacement item
Shampoo/Lotion	PAPER OR REFILLABLE DISPENSERS
Plates. Plastic coated	PAPER PLATES
Coffe cups. styrofoam	PAPER CUPS
Plastic clear portion cups	WASHABLE PLASTIC CUPS
Skeet shooting shells	BIODEGRADABLE

SOURCE: PETER G. WHELPTON, EXECUTIVE VICE PRESIDENT, ROYAL CARIBBEAN CRUISES "PREVENTATIVE WASTE MANAGEMENT", MIAMI 1994

DEERBERG SYSTEMS

FORERUNNER IN PHILOSOPHY

- ECOLOGICAL AND ECONOMICAL
- HIGHEST FLEXIBLE OPERATION
- WE CAN ALREADY FULFILL TODAY THE FUTURE RULES & REGULATIONS

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FORERUNNER IN TECHNOLOGY

- STATE-OF-THE-ART EQUIPMENT

- NEW DEVELOPMENTS FOR FUTURE NEEDS

  - VERTICAL 3-DECK ARRANGEMENT
  - AUTOMATIC DE-ASHING
  - GREYWATER TREATMENT

- FLEXIBLE SOLUTIONS FOR CUSTOMER REQUIREMENTS

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RELIABLE PARTNER

- WORLDWIDE AFTER SALES SERVICE - 24 HOURS

- TECHNICAL ASSISTANCE & TROUBLESHOOTING

- QUALITY IN TRADITION SINCE 1756

25

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Session 2 - Advanced Incineration Technologies

Advanced Combustion and Combustion Control for Small Incinerators

by Jan Sandviknes,
Norsk Energi, Norway

US - EUROPEAN WORKSHOP ON THERMAL
WASTE TREATMENT FOR NAVAL VESSELS

ADVANCED COMBUSTION AND COMBUSTION CONTROL FOR SMALL INCINERATORS

BY

JAN SANDVIKNES

BRUSSELS, BELGIUM
29-30 October 1997

Efficient and environmental combustion of waste depends on

the three T

TIME
TURBULENCE
TEMPERATURE

and some other parameters

Construction

Control system

Operation system

TIME

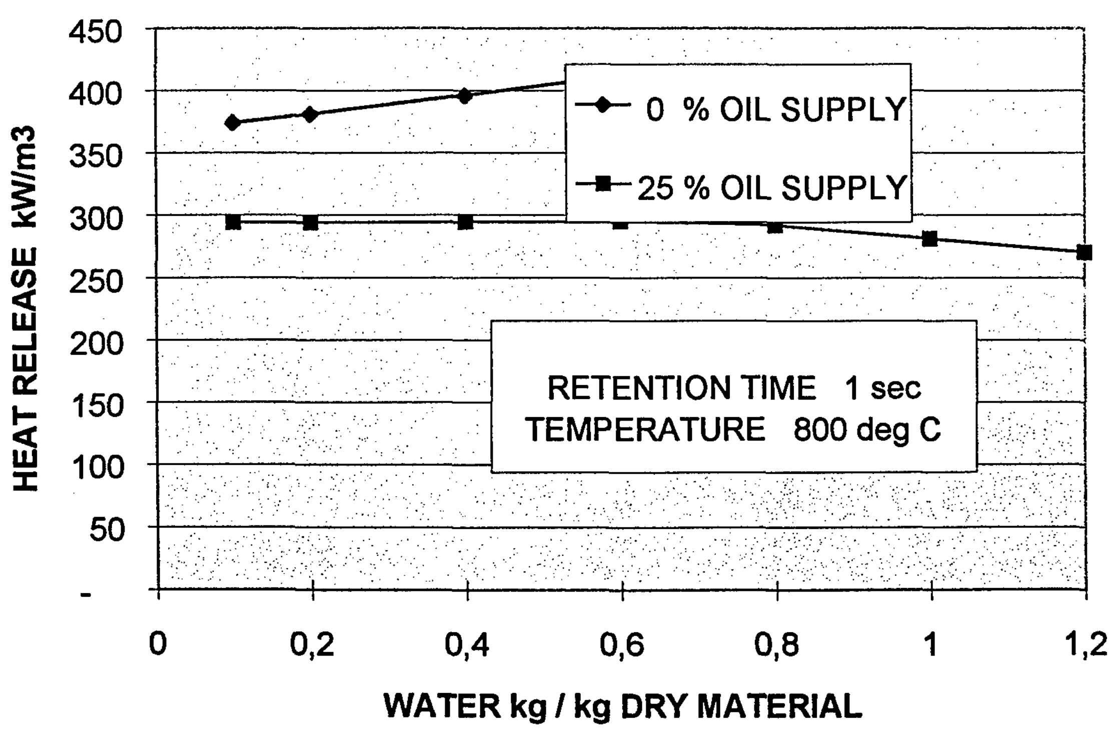
The gases must have a retention time of 1-2 seconds at a temperature of 800- 1100°C

How to achieve sufficient time ?

- **The heat release from waste must not exceed 300 to 400 kW pr m^3 combustion chamber at a temperature of 800 ° C and 1 second retention time for the gases**

- **By additional oil combustion, the specific heat release from waste must be reduced**

Figure 1 Maximum heat release



TURBULENCE

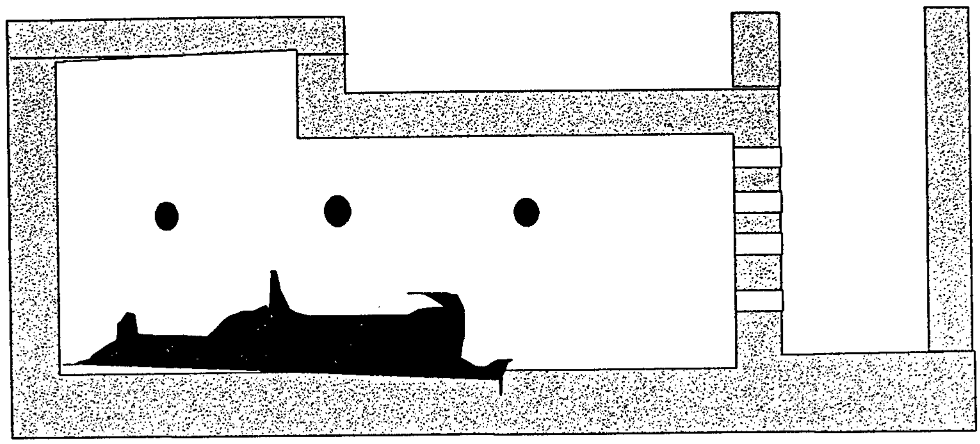
Turbulence means good mixing of oxygen and combustion gases from the waste.

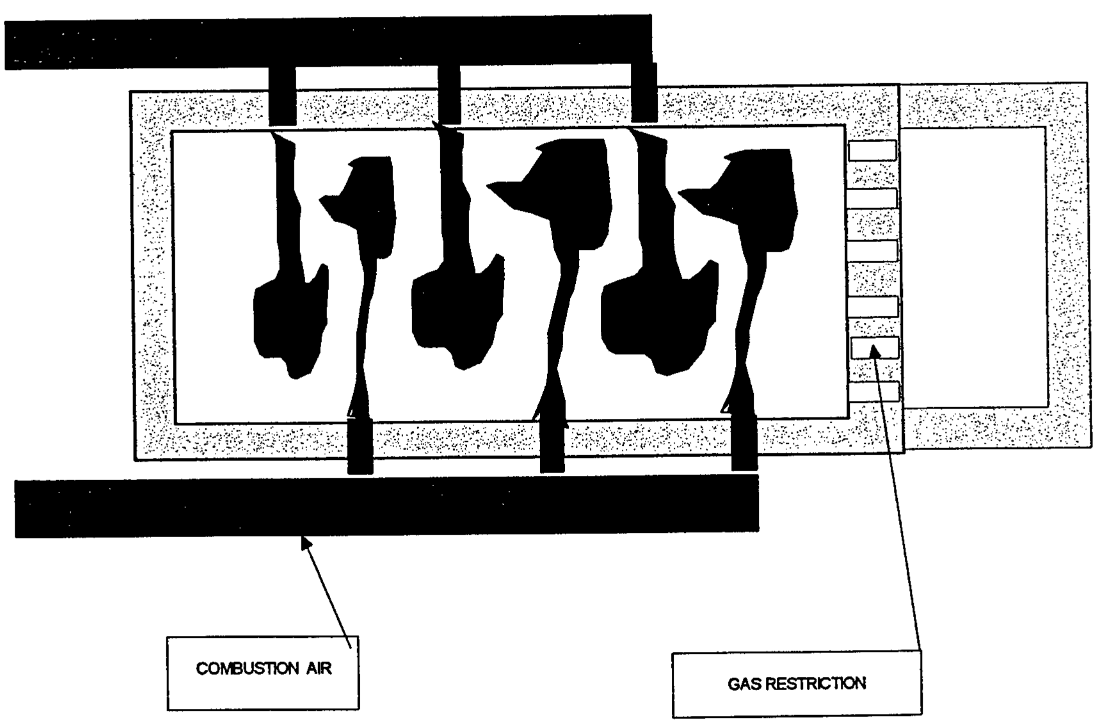
How to achieve good mixing ?

- **High velocity of combustion air**
- **Restrictions for the combustion gases**
- **The mixing must be good over the whole control range**
- **Mikropulsations may give good mixing**
- **Recirculation of gases is not the same as good mixing**

(Figure 2)

Figure 2 Examples of good mixing





TEMPERATURE

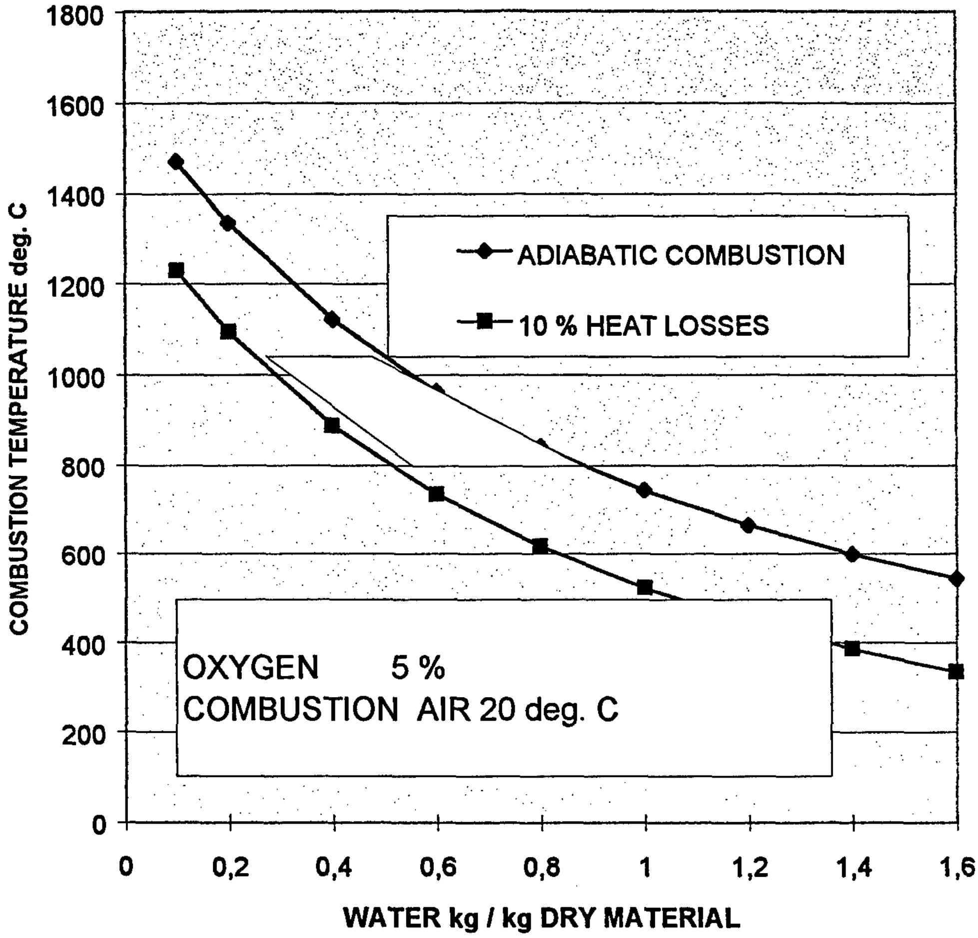
The combustion gases must be held at 800 - 1100 °C
at a retention time of 1 to 2 seconds

How to achieve desired temperature ?

- **Insulation of combustion chamber**
- **Controlling combustion air**
- **Preheating of combustion air**
- **Adding oil or gas to the combustion**
- **Drying of waste**

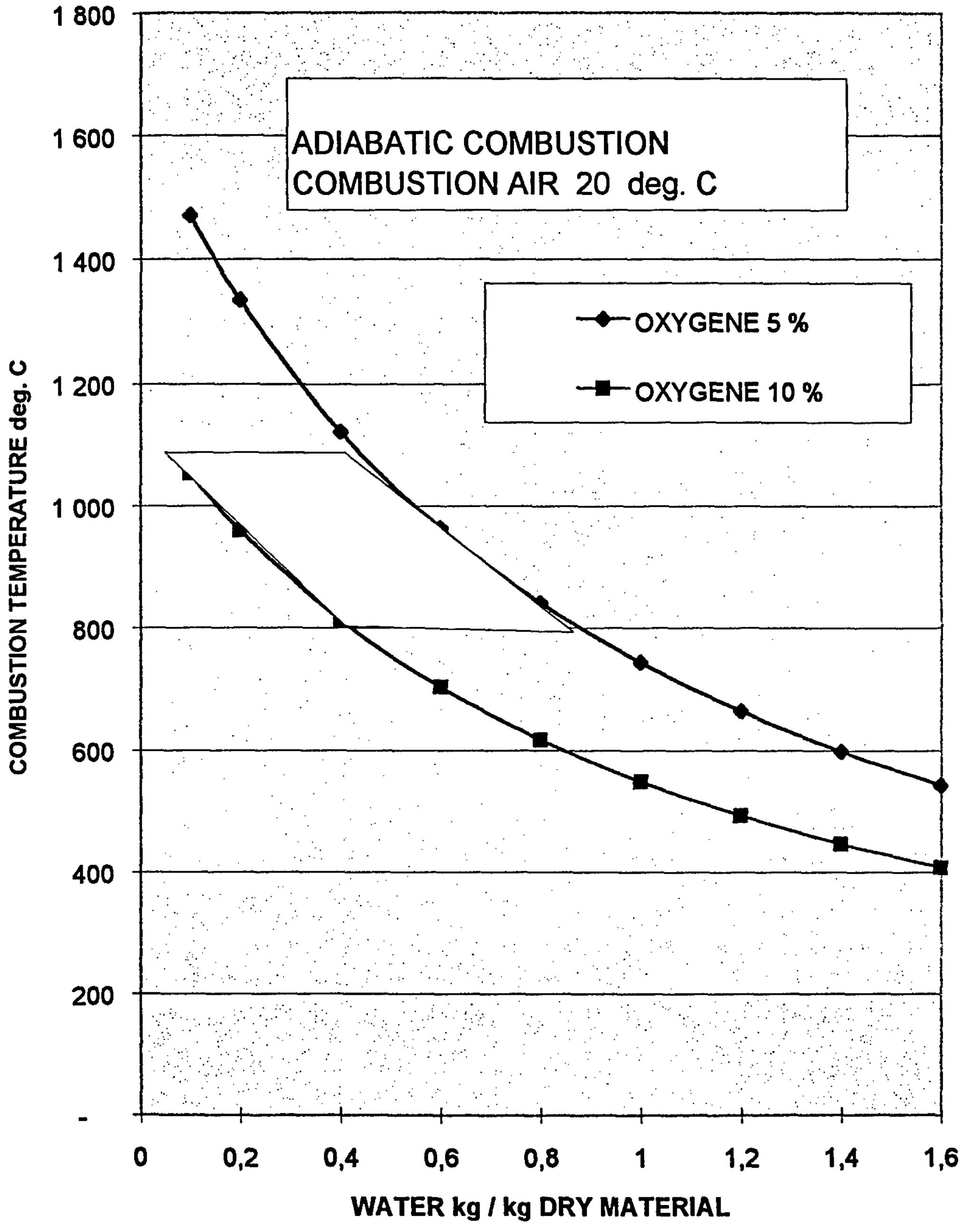
(Figure 3,4,5,6,7,8)

Figure 3 Insulation of combustion chamber



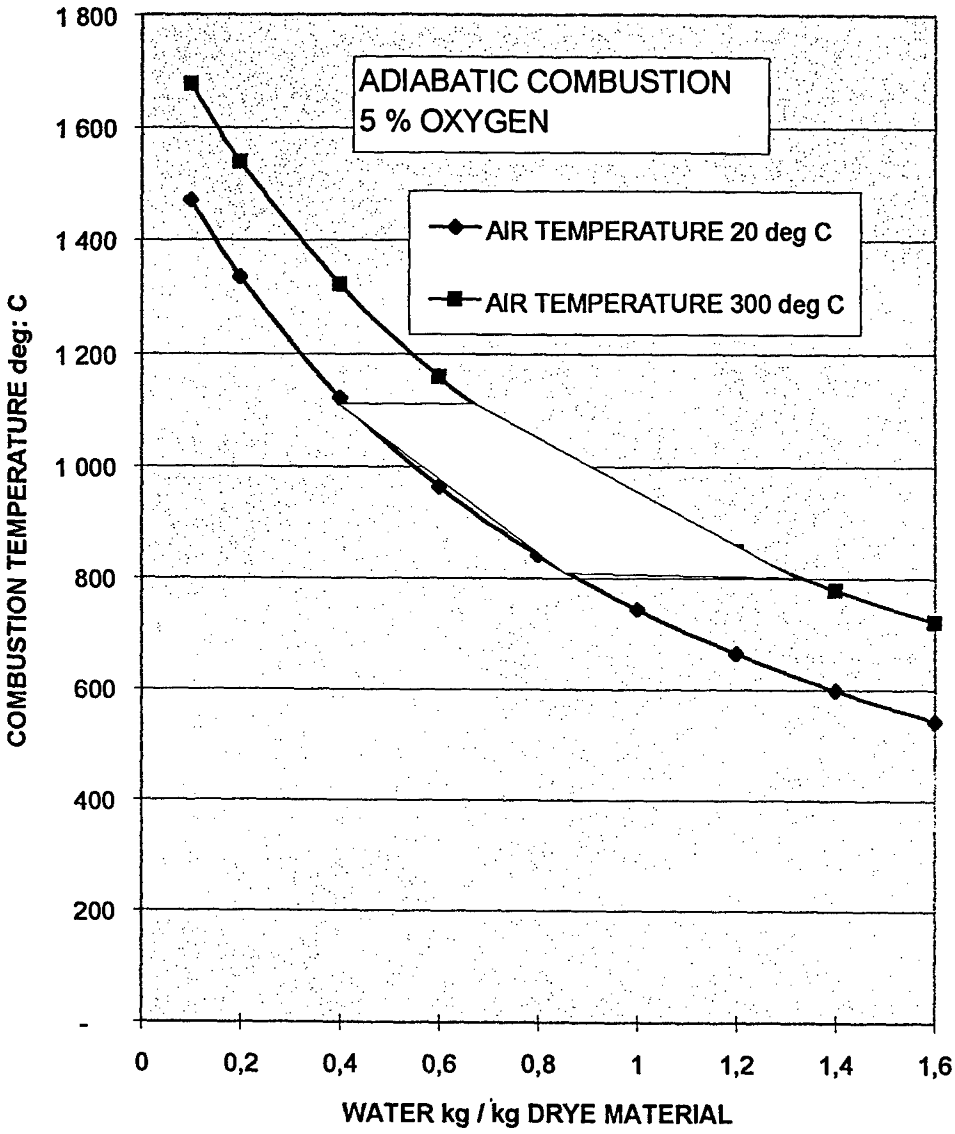
10 % heat loss from combustion chamber lower the combustion temperature by 220 °C

Figure 4 Controlling combustion air



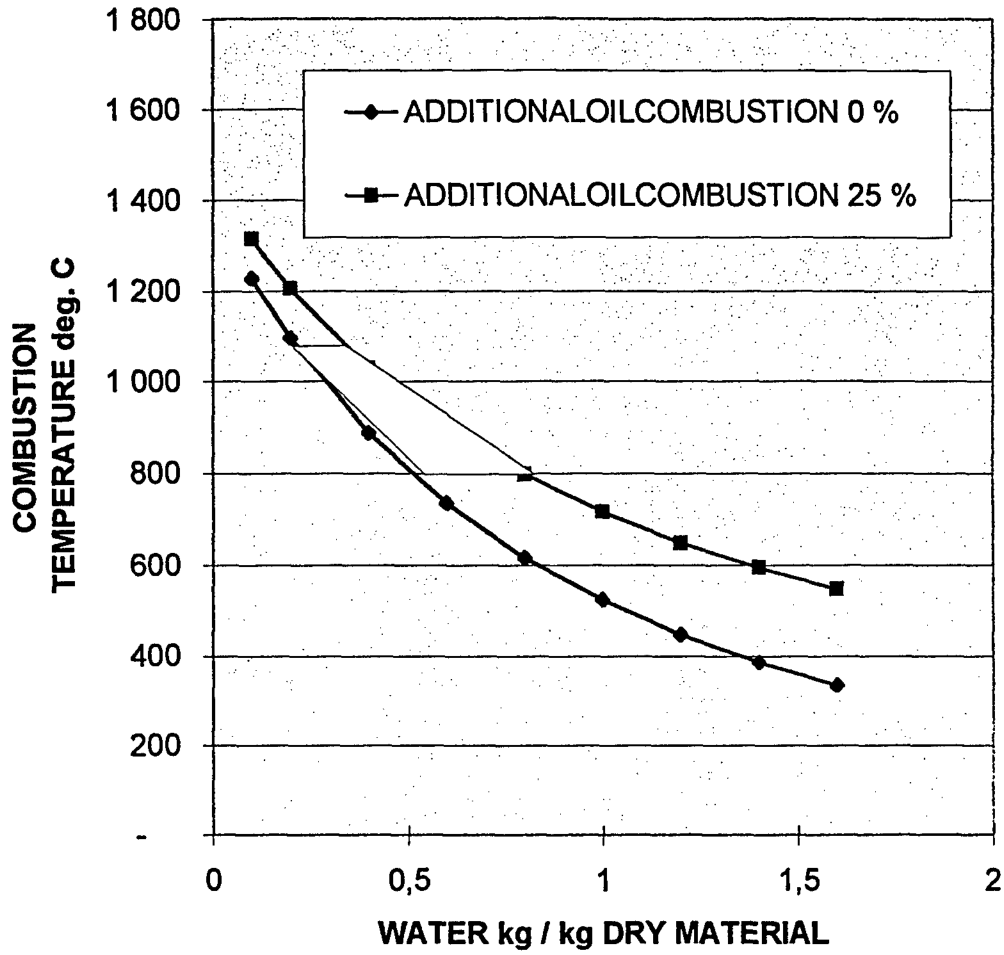
Reducing the O_2 from 10 to 5 % increase the combustion temperature by 300 °C

Figure 5 Preheating of combustion air



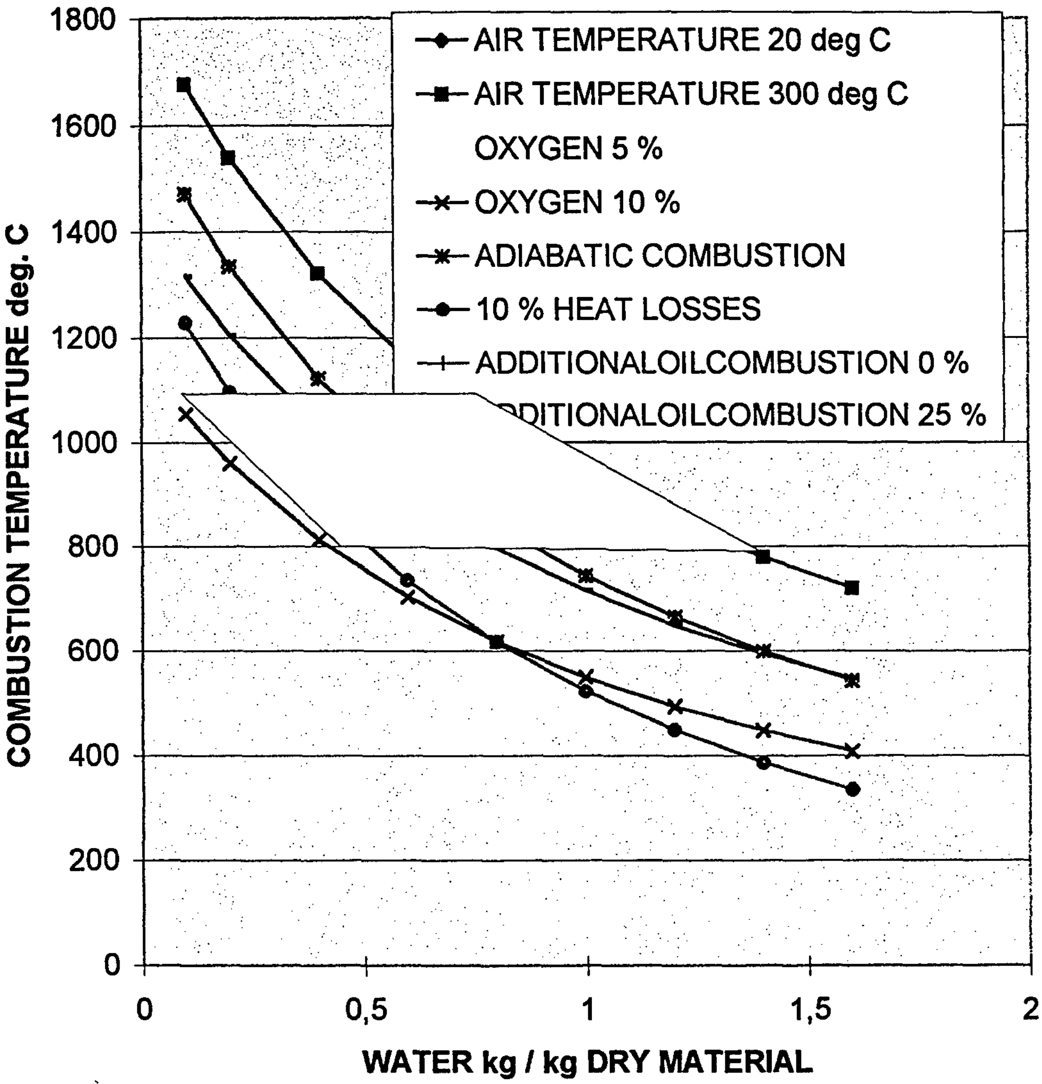
Preheating of combustion air 300 °C increase the combustion temperature by 220 °C

Figure 6 Adding oil or gas to the combustion



Increasing the oil supply by 25 % increase the combustion temperature by 180 °C

Figure 7 All together



Control systems

- **Control the input of waste - small portions**
- **Control the combustion air to the combustion chamber - 5 % oxygen in combustion gases**
- **Control the preheating of combustion air**
  (Figure 8, 9)

Figure 8 Controlling input of waste and air

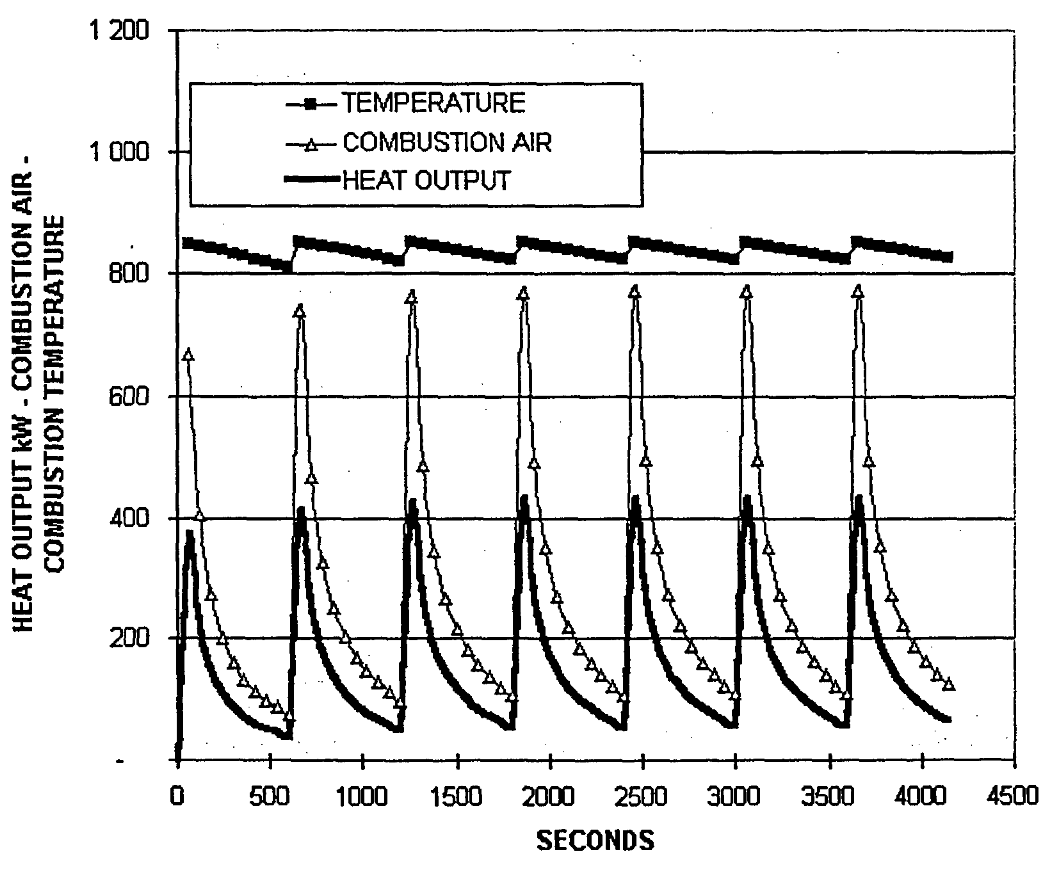
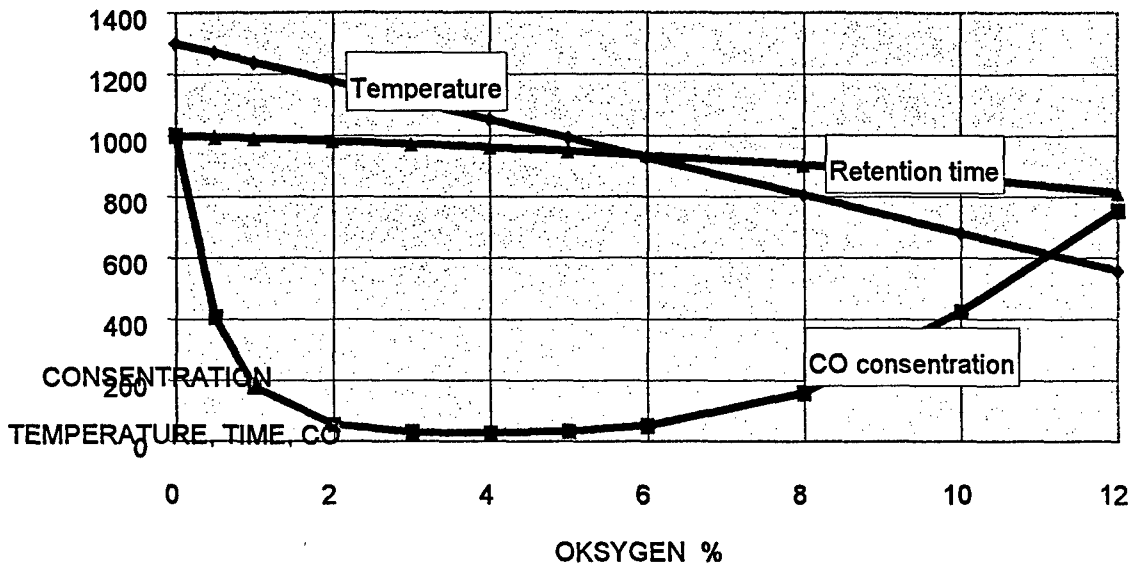
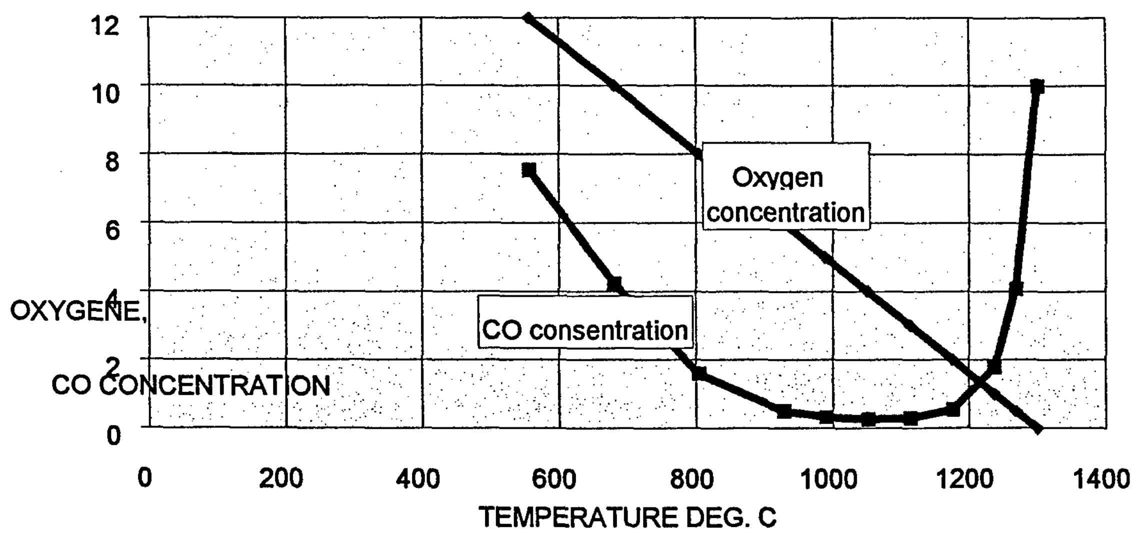


Figure 9 CO as a function of O_2 and combustion temperature





Construction

- Insulate the combustion chamber
- Sectional supply of combustion air
- Preheat the air

Operation and training systems

Every technical system will be incorrect operated if possible!

Training and education is of great importance.

Session 2 - Advanced Incineration Technologies

R & D in the United States on Incineration of Marine Waste

by Dr. Randy Seeker,
Energy and Environmental Research Corporation, USA

R&D IN THE UNITED STATES ON INCINERATION OF MARINE WASTE

Presented at

US-European Workshop

on

Thermal Waste Treatment for Naval Vessels

Brussels, Belgium

October 29-31, 1997

Presented by

Dr. Randy Seeker

Energy and Environmental Research Corporation

Coauthor

Dr. Klaus Schadow

Naval Air Warfare Center

OUTLINE OF TALK

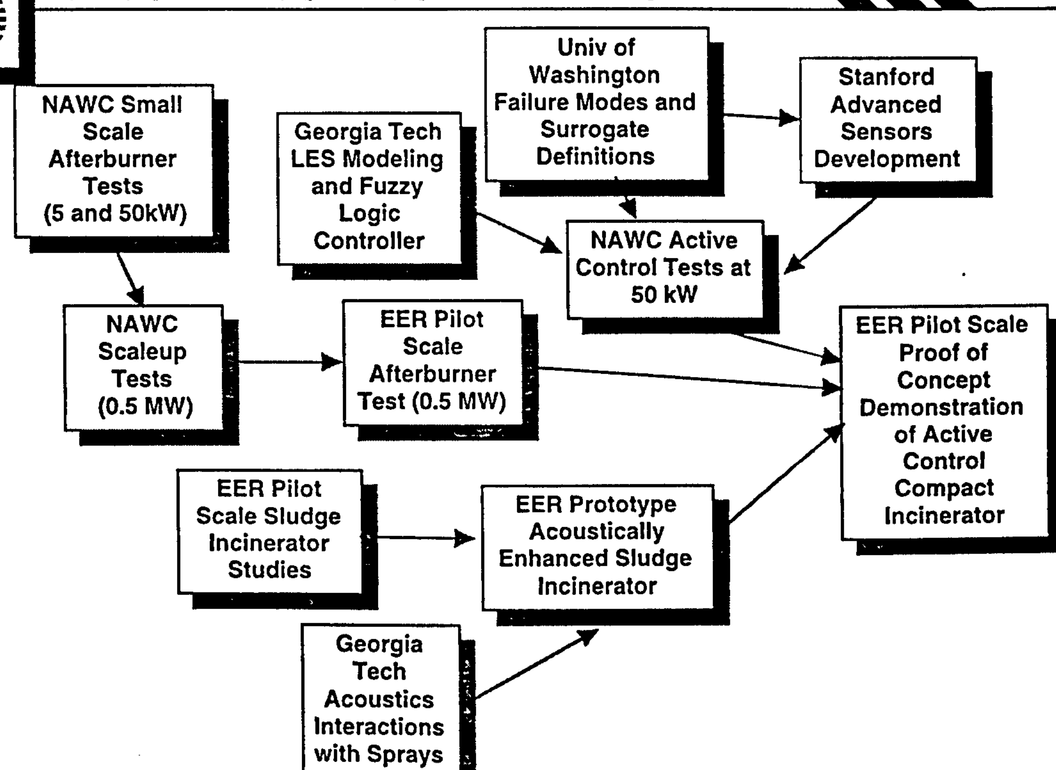
- Ongoing US R&D on Advanced Incineration Technologies
- NASA Program for Incinerators for Missions in Space
- SERDP Program on Advanced Thermal Treatment using Active Combustion Control
  - *Objectives*
  - *Resonant Acoustics*
  - *Acoustic Vorticity*
  - *Applications*
  - *Test Results*
- Summary

SERDP PROGRAM OBJECTIVES

- Develop advanced shipboard incinerator systems
- Key Characteristics
  - *Compact*
  - *Active Control*
  - *Burn Navy Wastes with Varying Compositions*
    - Liquid Wastes (e.g., black water, oily wastes)
    - Solid Wastes (e.g., paper, garbage)
  - *High Destruction Efficiency/Low Pollutant Emissions*
- Application Focus
  - *Navy "Vortex" sludge incinerator*
  - *Afterburner for Plasma ATD concepts*
  - *Integrated Solid Waste Thermal Treatment with Active Combustion Control*

Advanced Thermal Treatment using Active Combustion Control

SERDP PROGRAM OVERVIEW

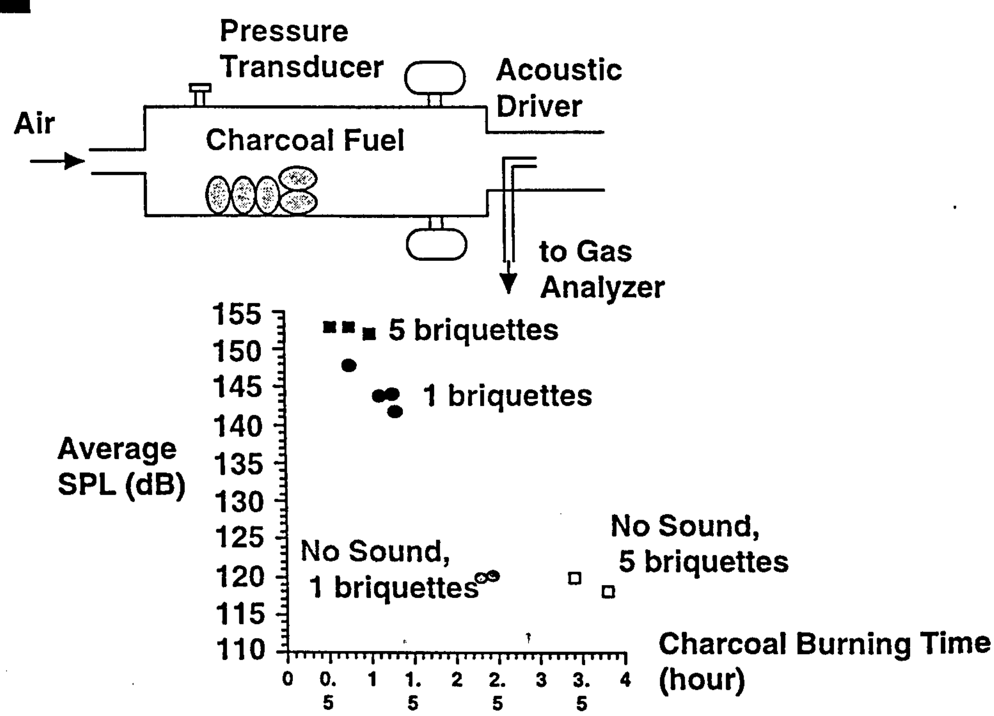


Advanced Thermal Treatment using Active Combustion Control

RESONANT ACOUSTIC CONCEPTS

- ❑ Resonant acoustic oscillation applied to combustion chamber to enhance burning rate
- ❑ Incineration in the presence of transverse acoustics
  - *increased combustion rate of cardboard by 300% and charcoal by 400%*
  - *degree of complete burning increased from 5 to 20% depending on air preheat*
  - *NOx and CO emissions changed with applications of acoustics*

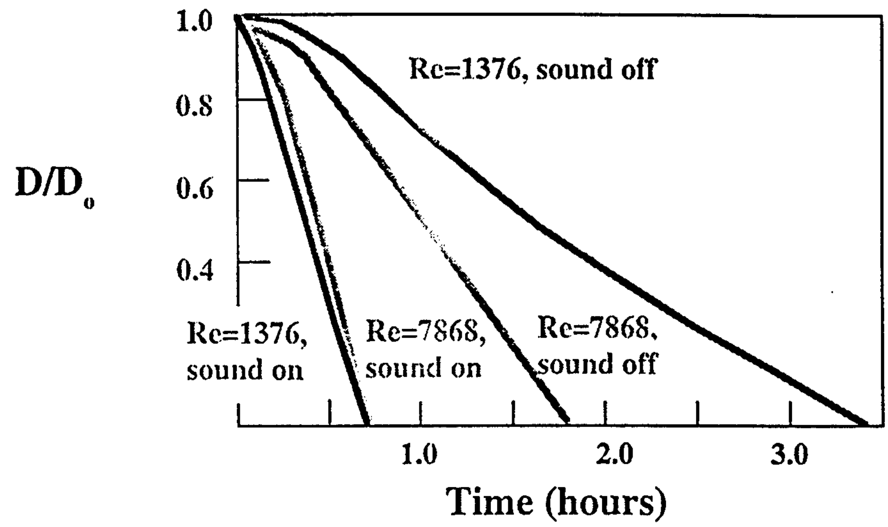
FUNDAMENTAL STUDIES



Advanced Thermal Treatment using Active Combustion Control

FUNDAMENTAL STUDIES

- ❑ Impact of acoustics
- ❑ Combustion of solid charcoal in air flow
- ❑ Oscillations at 1000 Hz and 155 dB



Advanced Thermal Treatment using Active Combustion Control

EFFECT OF RESONANT OSCILLATIONS ON ROTARY KILN OPERATION

- ❑ Enhancement of throughput rates in rotary kiln incinerators

	UNITS	TEST 1	TEST 2	TEST 3	TEST 4
PRODUCTIVITY	lb/hr	102.1	132.5	135	156
GAS ANALYSIS	O2 %	11.3	10.7	10.2	10.8
(STACK)	CO, ppm	14.3	37.7	8	28.6
	NOx,ppm	72.6	83	63	66.3

TEST 1. NORMAL OPERATION WITH CONVENTIONAL BURNER
TEST 2. MARGINAL OPERATION WITH CONVENTIONAL BURNER
TEST 3. MARGINAL OPERATION OF TEST 2 WITH PULSE COMBUSTOR
TEST 4. MARGINAL OPERATION WITH PULSE COMBUSTOR

Advanced Thermal Treatment using Active Combustion Control

LIQUID WASTE INCINERATION PROGRAM

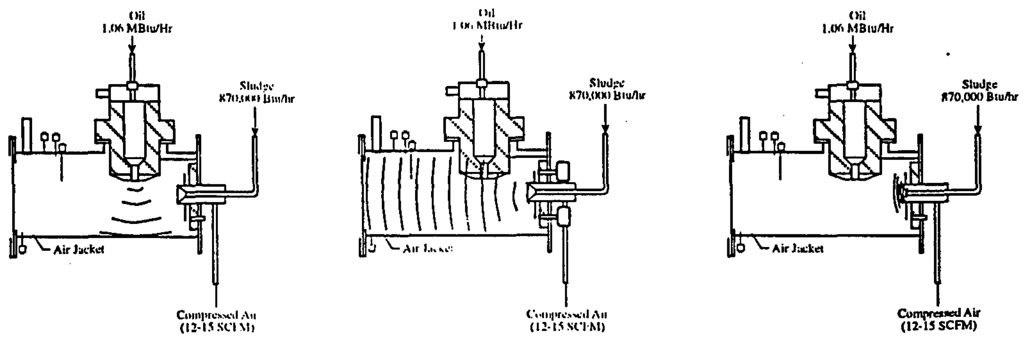
❑ **Purpose:**

- *Utilize acoustic excitation to enhance the blackwater sludge incinerator processing capacity/flexibility*
  - higher sludge throughput
  - higher solids loading
  - oily waste disposal

❑ **How:**

- *Develop controllable resonant combustor*
- *Evaluate interactions of resonance with spray*
- *Replicate blackwater sludge incinerator for baseline evaluation, acoustic retrofit, and performance evaluation*

ACOUSTIC APPLICATIONS

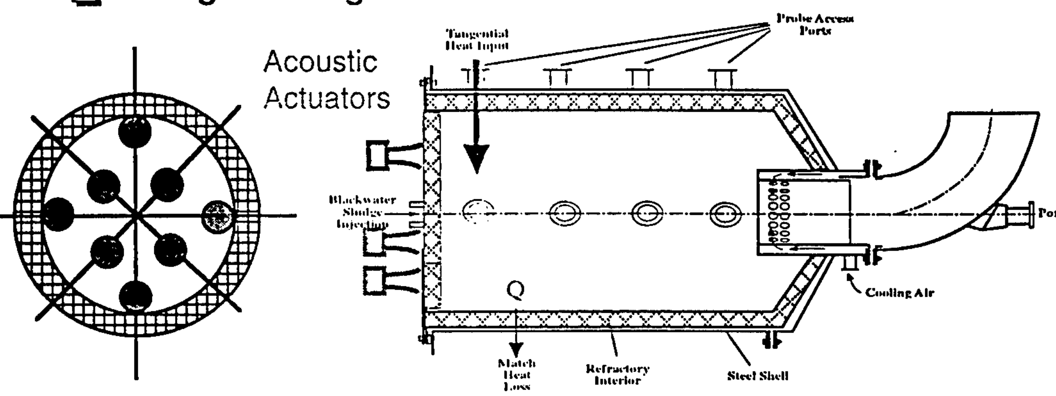


(a) Transverse (b) Longitudinal (c) Nozzle

Advanced Thermal Treatment using Active Combustion Control

EXPERIMENTAL SCALING

- Geometrically identical
- Matching heat loss (3 zones)
  - *one air passage with refractory v.*
  - *two air passages with radiation gap*
- Identical auxiliary burner
- Identical sludge nozzle
- Match exhaust quench rate (but not flow rate)
- Surrogate sludge

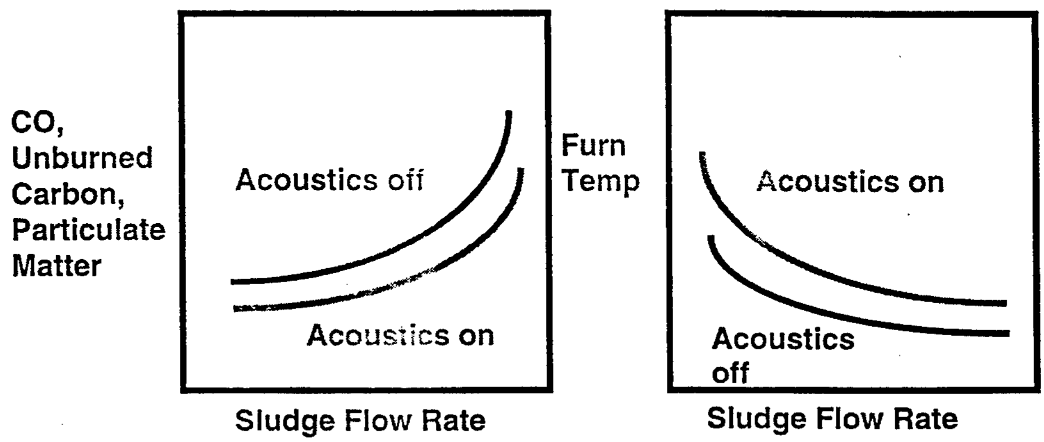


TEST PLAN FOR SLUDGE INCINERATOR

- Black Water Surrogate
  - *Water* 98%
  - *Dry Dog Food* 1.6%
  - *Toilet paper* 0.2%
  - *Salad oil* 0.2%
  - *Benzene* 100 ppm
- Variations
  - *Pure water (for initial testing for maximum flow rate)*
  - *Reduction in Water content*
  - *Addition of waste oils*

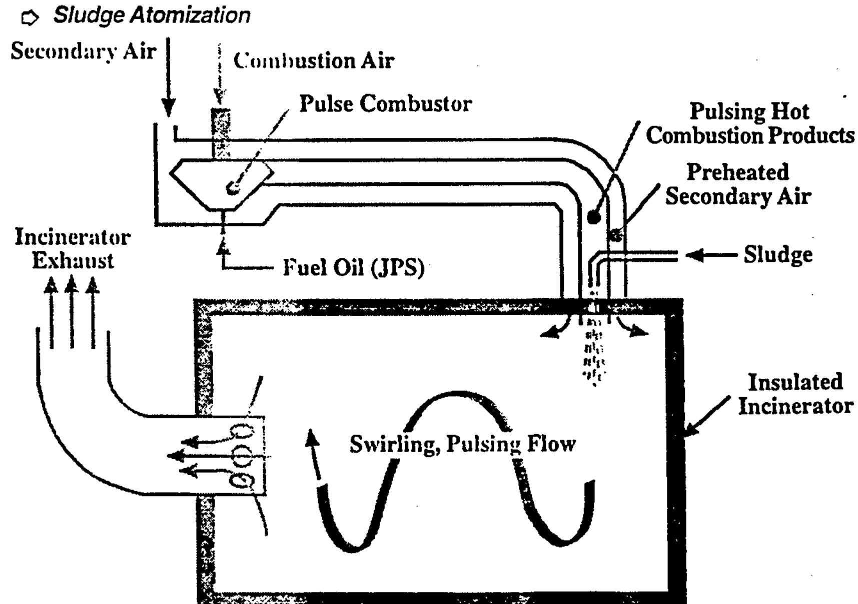
TESTING SCOPE

- Parameters
  - *Acoustic Operation (P, w, f)*
  - *Number and arrangements of acoustic devices activated*
  - *Vary sludge throughput*
  - *Nozzle Design (hollow cone v. solid cone)*



OIL BURNING PULSE COMBUSTOR

- Pulse Combustor Provides:
  - *All Heat Necessary for Incineration*
  - *Acoustic Driving*
  - *Sludge Atomization*



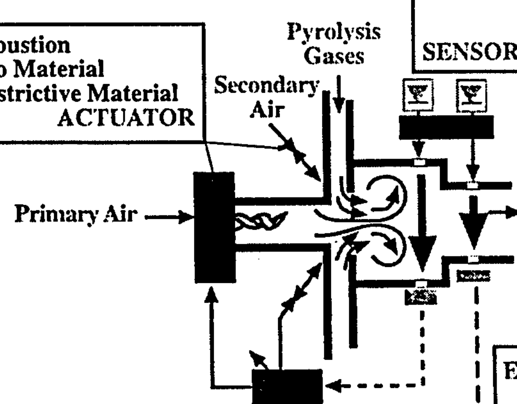
FULL SCALE ACOUSTIC VORTICITY CONCEPTS

ACTIVE CONTROL COMPONENTS FOR COMPACT AFTERBURNER

- Pulsed Combustion
- Piezo-Electro Material
- Magneto-Restrictive Material

ACTUATOR

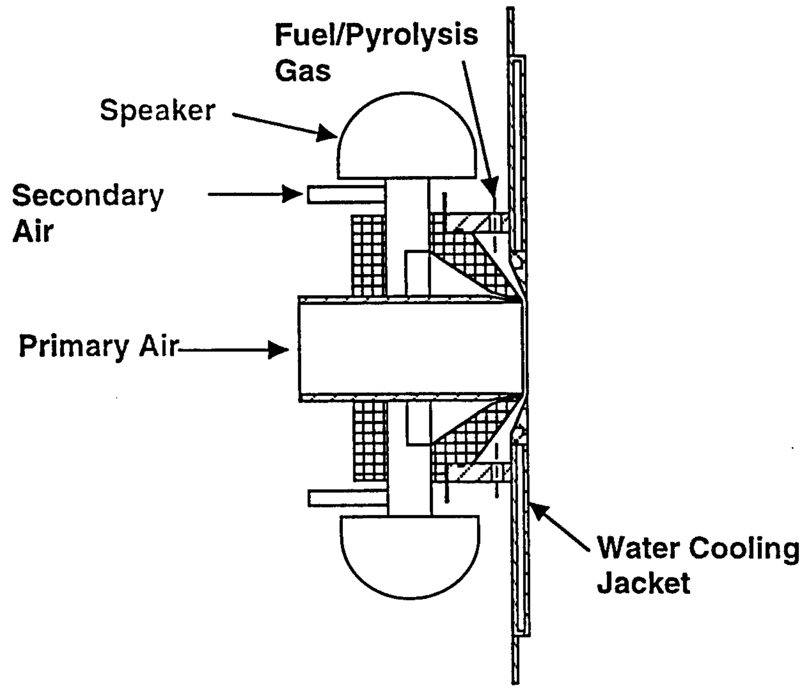
SENSOR
- Multiplexed Diode Laser System
- Temperature, H_2O
  - Real Time, 250 Hz
  - InGaAsP, 1840 and 1390 nm
- CO, Benzene
  - External Cavity Diode Laser
    - Probe; Multi-Path Cell 1560 nm
    - Sb-Based Laser; DFG Wave Extension; 2300 and 2400 nm



EMISSION
- Relationship between Toxic Compounds and Surrogates which can be Monitored with Diode-Laser Sensors
- Identification of Failure Modes

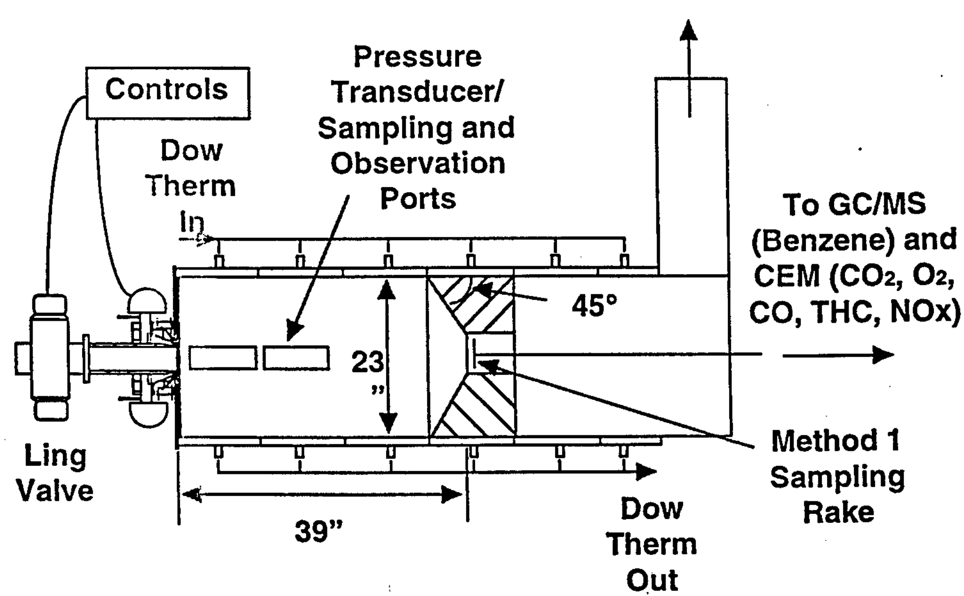
CONTROLLER
- Large Eddy Simulation (LES)
  - 1-D, Dynamic Model
  - Phenomenological Model
  - Neural Net and/or Fuzzy Logic Controller
- Approximate Modeling and Parameter Identification

AFTERBURNER DETAILS



Advanced Thermal Treatment using Active Combustion Control

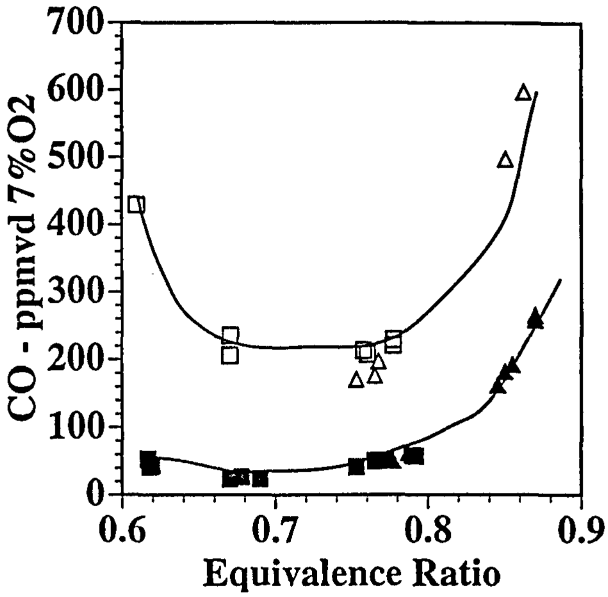
400 KW TEST ARRANGEMENT



Advanced Thermal Treatment using Active Combustion Control

400 KW TESTS

- Impacts of Forcing and Stoichiometry on CO emissions (Ethylene/Benzene in Nitrogen)



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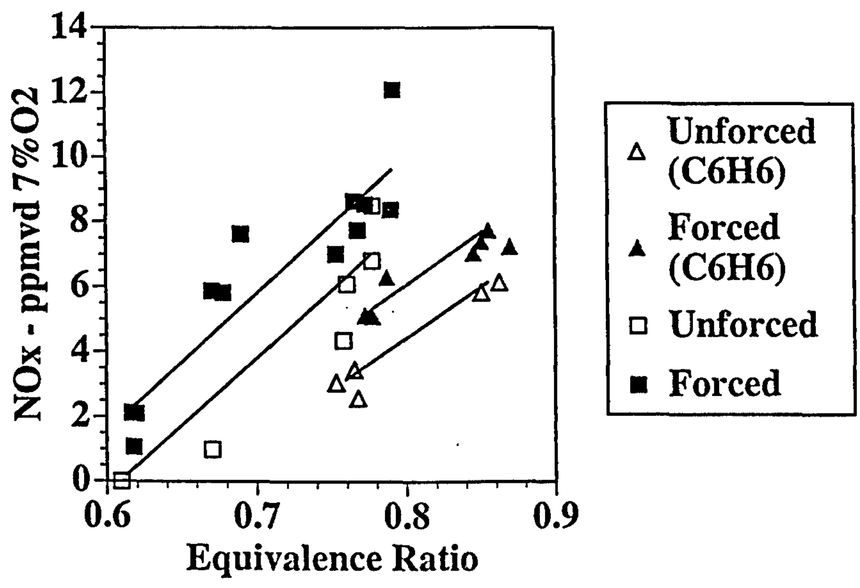
400 KW TESTS

- Impact of Stoichiometry and Forcing on NOx



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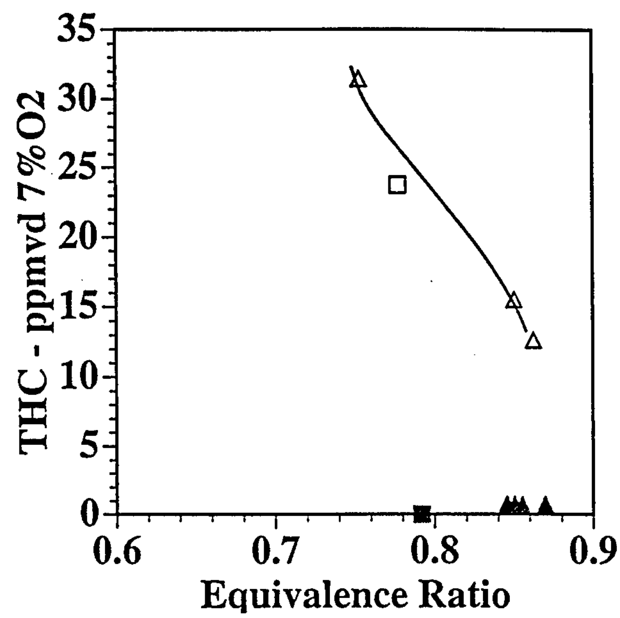
400 KW TESTS

- Impact of Stoichiometry and Forcing on THC



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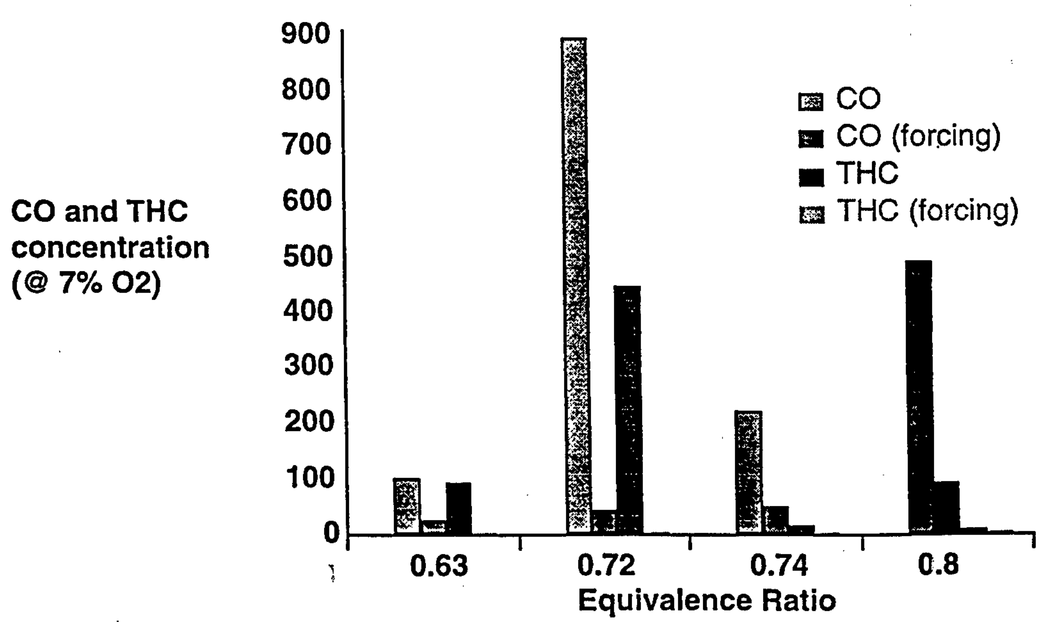
400 KW TESTS

- Modified Primary Air



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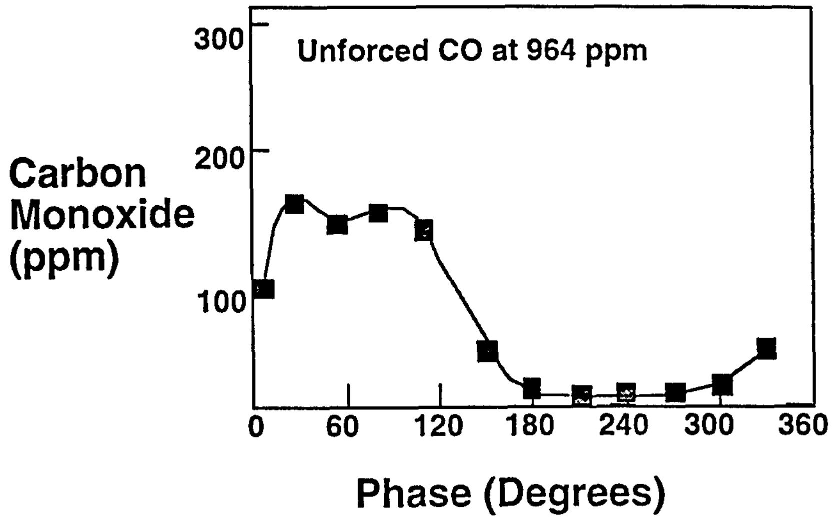
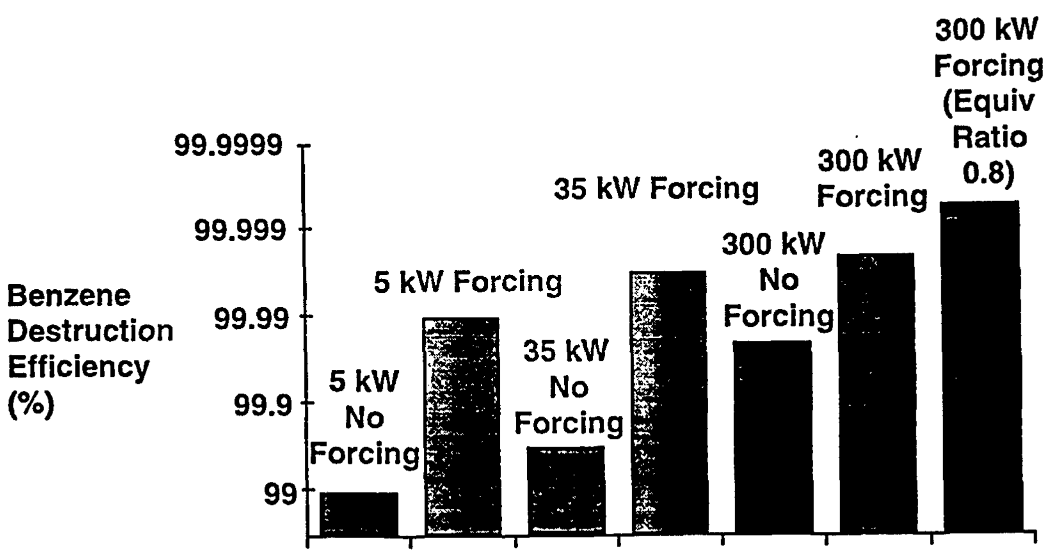
COLD FUEL TESTS

- ❑ Impacts of Phasing between primary and secondary air forcing on CO
- ❑ 50 kW tests on ethylene/benzene/nitrogen

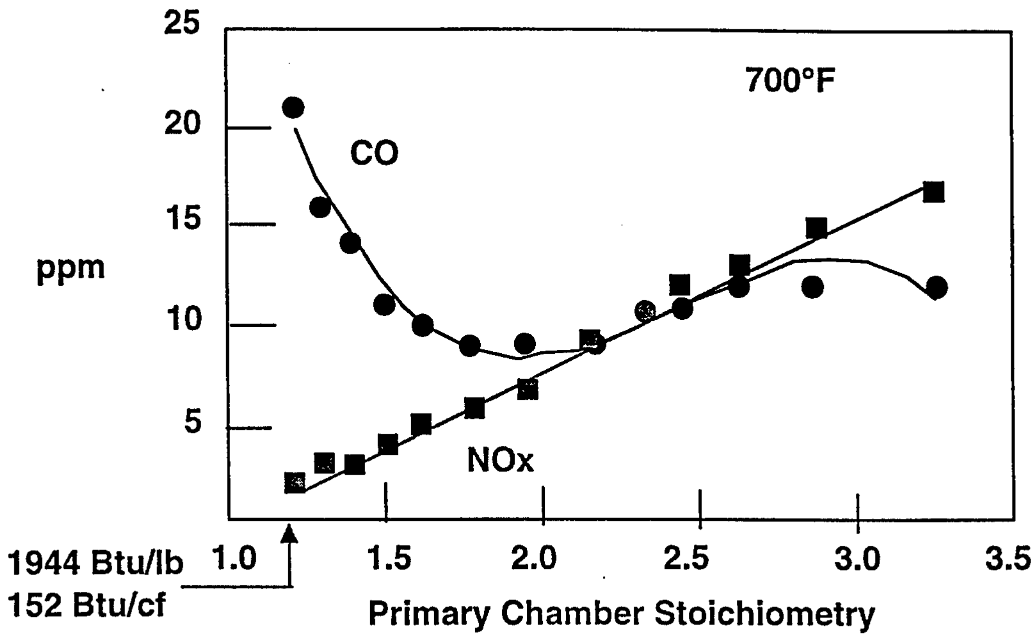


SCALE UP TESTS

- ❑ Impact of Scale



LOW BTU HOT PYROLYSIS GAS TEST



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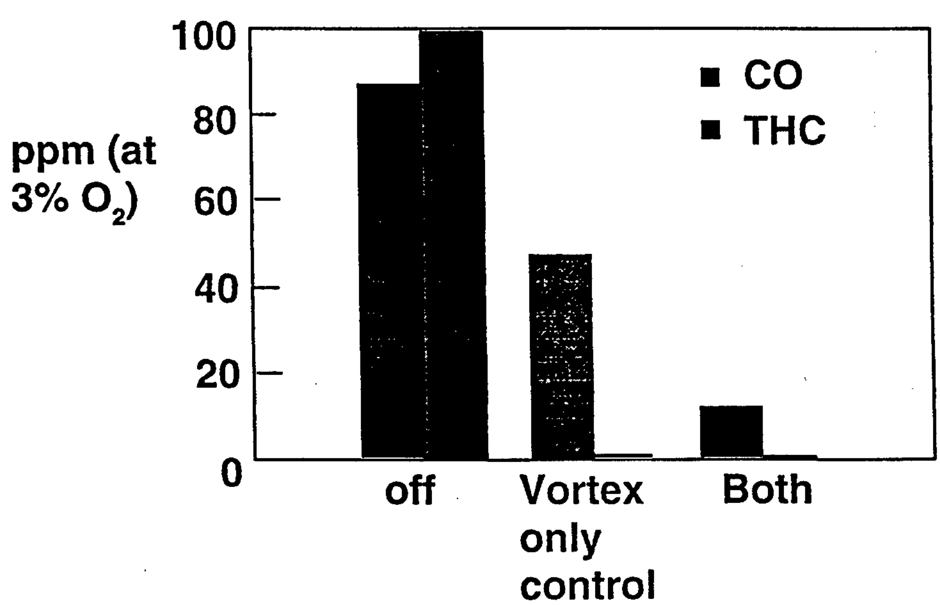
LOW BTU HOT PYROLYSIS GAS TEST

- ❑ $CO+H_2+H_2O+N_2$ Hot Waste Surrogate at 115 Btu/cuft



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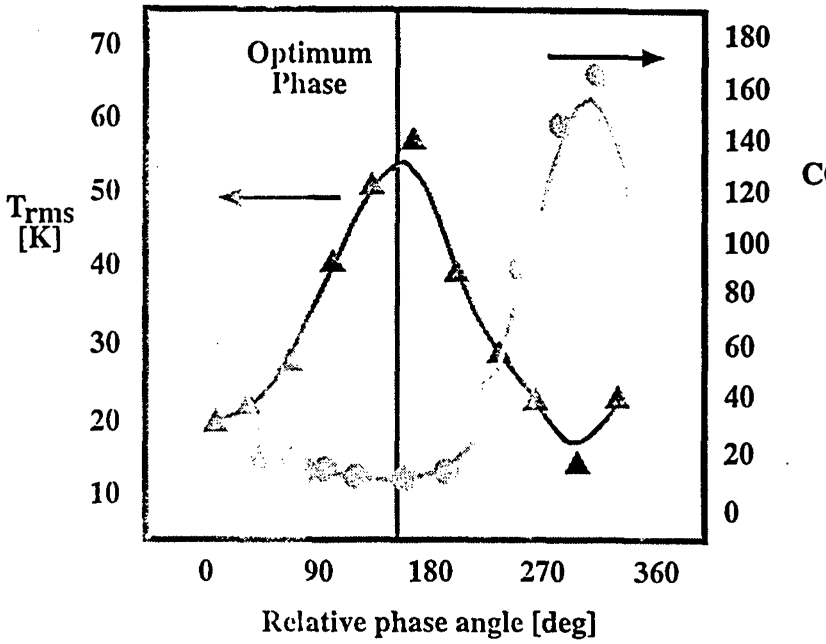
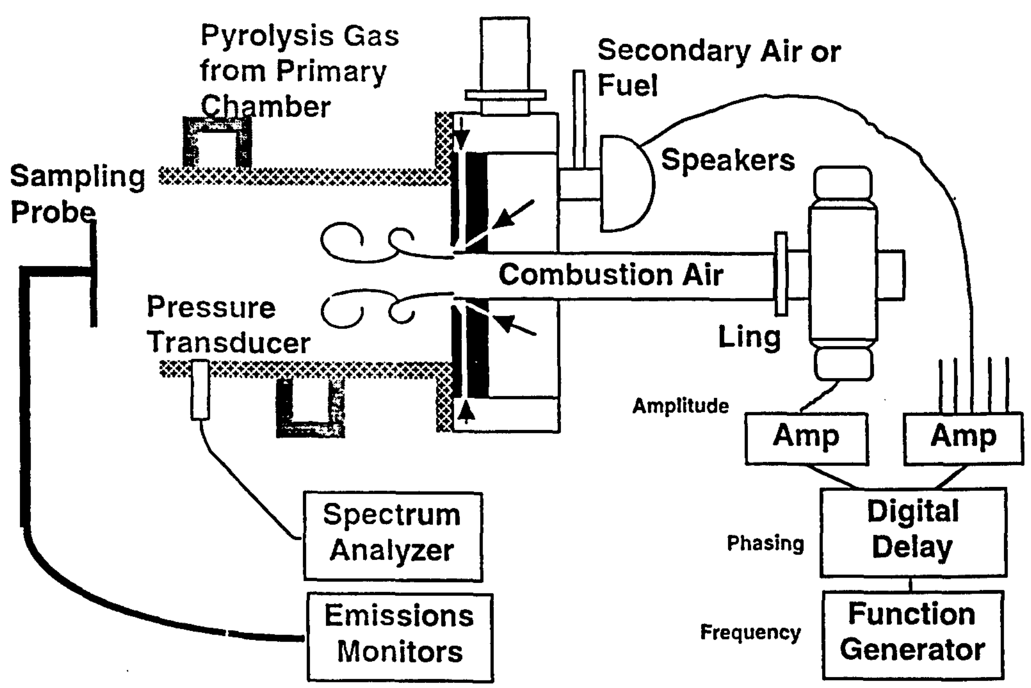
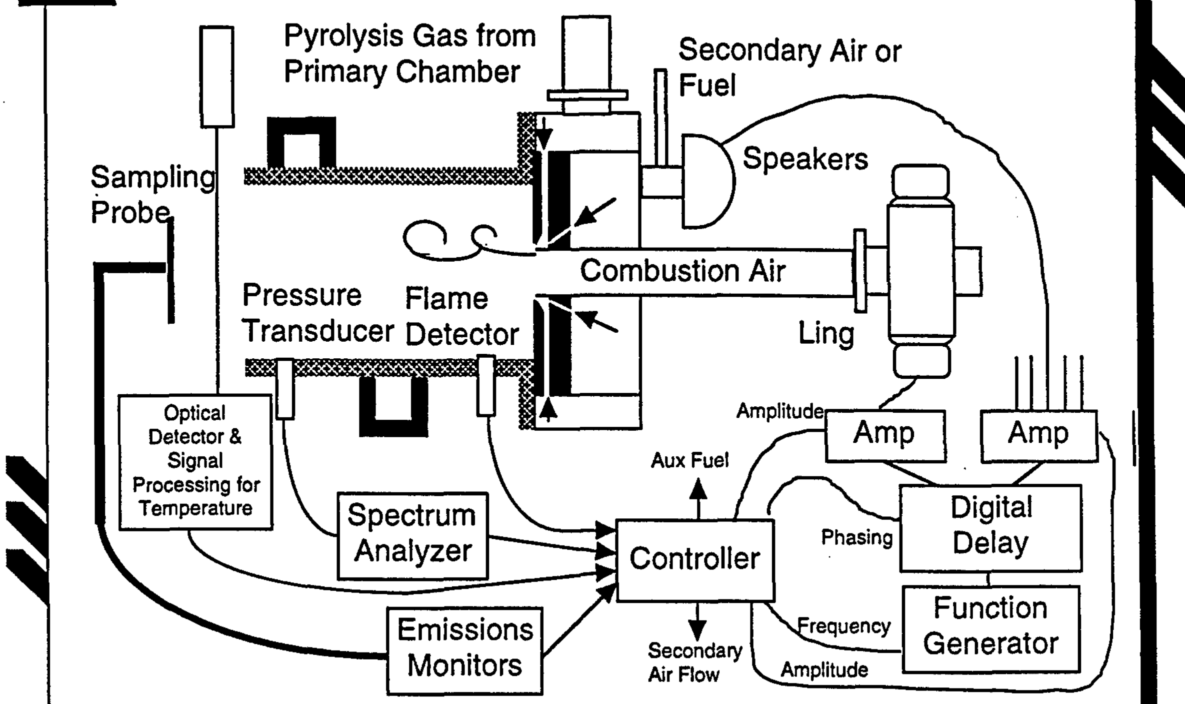
CONTROLLER PARAMETERS



PRELIMINARY CONTROLLER CONCEPT

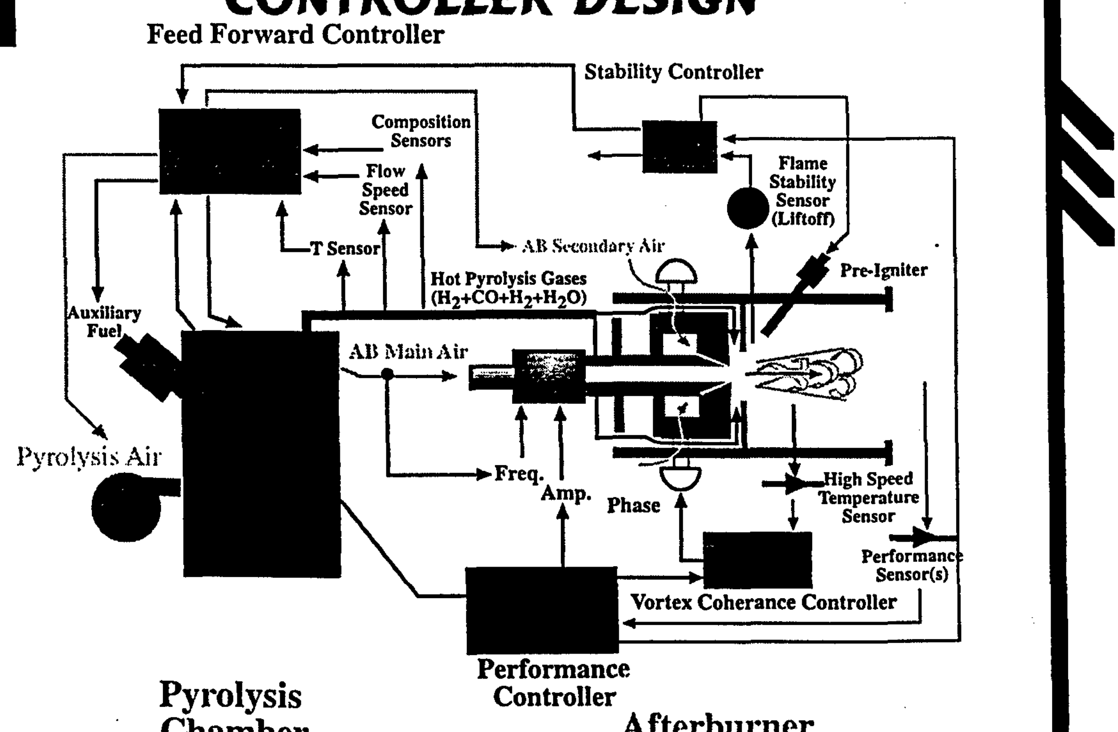


ADVANCED CONTROLLER CONCEPT



Advanced Thermal Treatment using Active Combustion Control

CONTROLLER DESIGN



Advanced Thermal Treatment using Active Combustion Control

SUMMARY

- Ongoing R&D in incinerators is leading to significant improvements in
  - *burning rates of solids and liquids in presence of acoustic fields*
  - *compact active controlled afterburners using controlled vortices*
  - *continuous emission monitors*
  - *air pollution control*
- Full scale demonstrations are underway or planned
  - *black water incinerators*
  - *afterburners for pyrolysis chambers*
  - *integrated solid and liquid waste compact incinerators*

<u>Session 2</u> - Advanced Incineration Technologies

Shipboard Liquid Waste Thermal Destruction

by Carl M. Adema,
Naval Surface Warfare Center Carderock Division, USA

SHIPBOARD LIQUID WASTE THERMAL DESTRUCTION

presented by

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at

US-European Workshop

THERMAL WASTE MANAGEMENT ON NAVAL SHIPS

29-31 October 1997
Brussels, Belgium

Introduction

Only one liquid waste incinerator has been used on US Navy ships - the vortex incinerator. This incinerator was purchased with the DD963/DDG993 class destroyers as part of the ship procurement. Each of the 35 ships in these two classes has two vortex incinerators. These incinerators were designed by T-Thermal (formerly Trane-Thermal) as a light-weight, small footprint incinerator to destroy the blackwater produced on the ship. The blackwater is collected by vacuum and contains approximately 2% solids. The incinerators are designed to burn blackwater at 30 gallons per hour using 7 gallons per hour of JP-5 (jet fuel). Under these conditions, the incinerators were designed to operate approximately 10 hours per day.

Laboratory testing of the vortex incinerators confirmed that the incinerator met air emission standards and performance requirements. After several years of operation, a series of modifications were made to the vacuum collection system and the vortex incinerator. These modifications included substitution of sea water eductors in place of vacuum pumps, sludge nozzle modification, modification of ash doors and spark plug cooling, and improved incinerator liner.

However, after initial training and logistical support the units were allowed to deteriorate. By the late 1980's, the vortex incinerators were reported with overheating problems, a lack of spare parts, and inconsistent maintenance and training. Changes to the ash cleanout door had resulted in the door glowing red hot during operation. Overheating caused the liner to warp, and the use of saltwater to flush the urinals and commodes resulted in hot corrosion which rapidly produced holes in the liners.

As a result of the need for liquid waste thermal destruction, the Naval Sea Systems Command (SEA 03R16) has sponsored the development of a liquid waste incinerator based upon the vortex design. As the first step in the development effort, Carderock Division, Naval Surface Warfare Center (CDNSWC) in close coordination with the Naval Sea Systems Command (SEA 03L13) identified the causes for the poor performance of the existing vortex incinerators. Investigation of the overheating problem, revealed that corrosion products and fine ash had built up in the cooling air passages. During periods of inactivity, condensation formed in the cooling passages and fused the ash and corrosion products into a solid mass, which prevented the passage of cooling air. In some cases, a third of the liner was uncooled. Contributing to the overheating was the use of insulation on areas of the liner, which were not intended to be insulated. This resulted from a change in the supplier of the liners.

The net result of these problems - design deficiencies, lack of maintenance, and poorly trained operators - was a general reputation that the vortex incinerators did not work. However, after two incinerators on the USS THORN (DD 988) were completely refurbished and the design flaw was corrected by cleaning the cooling passages, the incinerators on USS THORN no longer overheated and they operated flawlessly during an entire six month deployment.

Remedies for many of the vortex incinerator problems had been identified by the Naval Sea Systems Command (03L13). In addition, CDNSWC identified remedies to the overheating problem and upgrades to the ILS documentation are planned for implementation into the Fleet by the Naval Sea Systems Command (SEA 03L13) through ship or machinery alterations.

Regulatory Requirements

The International Maritime Organization publishes international environmental regulations in a series of MARPOL Annexes. Annex IV sets discharge standards for blackwater and graywater discharges in coastal waters and "special areas". Annex I sets discharge standards for bilgewater discharges in coastal waters and "special areas".

IMO is developing environmental standards for shipboard incinerators. Generally, these standards are applicable to solid waste incinerators; however, the air emission requirements could also be applicable to liquid waste incinerators. These standards limit the carbon monoxide concentration in the flue gas to 465 ppm and limit the opacity of the flue gas to 20%. The vortex incinerator is ideally suited to meet these standards. It burns JP-5 in a well-designed fuel oil burner, which can easily meet the CO standard. The liquid wastes contain 98% water, which does not contribute to the emissions. The vortex design inherently removes particulate matter from the exhaust gas stream. As a result, the vortex incinerator, as originally designed and operated, meets emission requirements.

Liquid Waste Destruction Need

The need for the destruction of the liquid waste residues grows from a combination of both regulatory and ships mission requirements. The ship's mission requires that it operate in the MARPOL "Special Areas" for extended periods of time. In addition, many foreign ports do not provide pier services for liquid waste disposal or the cost of these services is becoming prohibitively high. The combination of discharge standards within MARPOL "Special Areas" and ship's mission requires that blackwater, graywater, and bilgewater be treated onboard the ship to produce an effluent that meets the discharge standards. However, after the treatment process a residue remains. The volume of the residue is such that it cannot be stored onboard for the entire mission duration. It contains approximately 2% solids from the blackwater and graywater and approximately 1000 ppm of oil from the bilgewater. A means of destroying the residue is needed.

Integrated Liquid Waste Concept

The need for extended mission duration, shore independence, and the potential payoff of reduced cost of liquid waste disposal leads to an integrated concept for the treatment of all non-hazardous liquid wastes onboard the ship. This concept is shown in Figure 1.

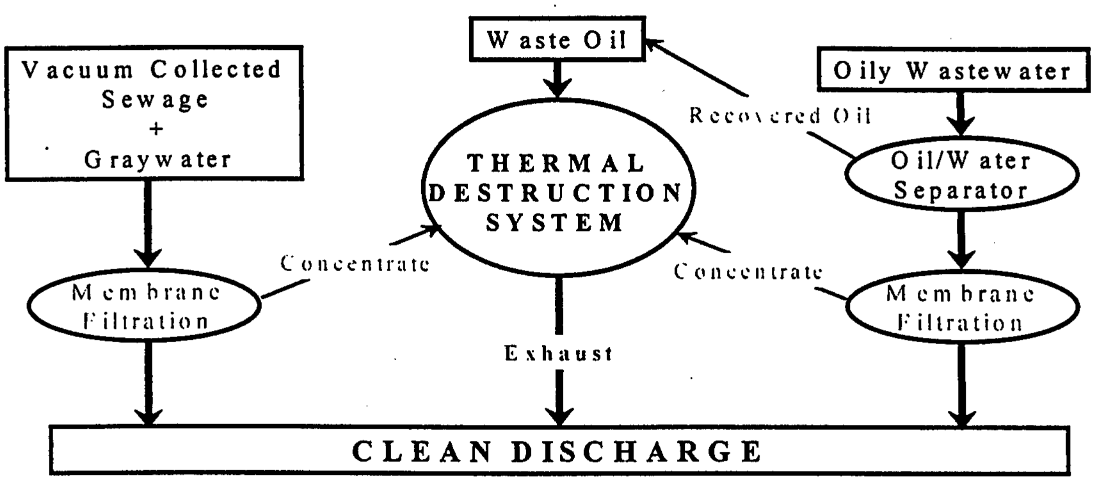

Figure 1 – Integrated Liquid Discharge System Concept

It involves the collection of blackwater by a vacuum collection system. The graywater is centrally collected and filtered using polymeric ultrafiltration membranes. Recent laboratory results indicate that the solids in the graywater can be concentrated at least 20 times. The effluent from the ultrafiltration membranes is treated to meet fecal coliform standards. The concentrate is stored onboard. Bilgewater is treated using oil/water separators to remove free oil, which is stored in a waste oil tank. Changes in ship design and operation over the past one to two decades have changed the characteristics of bilgewater to such an extent that the conventional oil/water separators can no longer reliably meet the discharge standards. As a result, ceramic ultrafiltration membranes are being developed to treat the effluent from the conventional oil/water separators. This process results in the concentration of the oil in the effluent of the OWS by a factor of 100 times. The central component of the integrated liquid waste treatment system is a thermal destruction device, which will destroy the vacuum collected sewage, the concentrates from the ultrafiltration processes, and the waste oil.

Upgrade of Vortex Incinerator

The vortex incinerator is a logical candidate for the destruction of the blackwater/graywater/bilgewater residue. It is, by its very design, compact and lightweight for warship applications. It is marinized for shipboard operation and has demonstrated that it can efficiently destroy liquid wastes when properly maintained and operated. A survey of marine and shore-based liquid waste incinerators has shown that the vortex incinerator is still state-of-the-art in liquid waste destruction.

The shipboard vortex incinerator uses a JP-5 burner, which fires, tangentially at one end of a cylinder, which is approximately 23 inches in diameter. The blackwater is sprayed axially into the center of the cylinder on the same end as the burner. The blackwater spray intersects the burner flame where the water is rapidly evaporated and the organic material is combusted. The exhaust gases swirl the length of the cylinder (approximately 36 inches) and exit the end opposite the burner on the cylinder axis. Ash remains inside the cylinder from which the operator periodically removes it.

The research and development objective, then, is to increase the capacity of the vortex incinerator to destroy the concentrated contaminants from graywater/blackwater/bilgewater liquid waste. With the concentration factors which have been achievable through the use of ultrafiltration membranes, the capacity of the vortex incinerator on a DD 963 Class destroyer would need to be increased by approximately 50% to destroy all of the liquid wastes. Therefore, a research and development program sponsored by the Naval Sea Systems Command (SEA 03R16) has been initiated by CDNSWC which will upgrade the existing vortex incinerator and demonstrate its ability to destroy all the liquid wastes on a DD 963 Class destroyer.

This program will involve thermodynamic and computational fluid dynamic (CFD) modeling of the vortex incinerator, fabrication of an engineering development model of the vortex incinerator, and evaluation of design upgrades in the laboratory and onboard ship.

Thermodynamic modeling has shown that the existing vortex incinerator capacity can be increased by 50% within the same footprint by increasing the fuel rate by 3 gph and by increasing the combustion air from 740 CFM to 1250 CFM. This would require an increase in the combustion and cooling air blower from 7.5 hp to 20 hp. Initial calculations predict a temperature increase of 10 degrees F within the incinerator and an increase in the exhaust gas flow from 1720 ACFM to 2450 ACFM. A computational fluid dynamics model has been developed and has operated in the evaporative and combustion modes i.e. evaporating water without any solids and combusting solids in the liquid waste stream. The results of the computational fluid dynamics model using temperature data from early testing of the incinerator are shown in Figure 2.

These results show the temperature patterns in the incinerator and are consistent with internal temperature measurements taken within the incinerator. Calibration and validation of the CFD model will be achieved using data from operation of the engineering development model in the laboratory. Then, changes in fuel and waste flow rates will be simulated mathematically and the effects on temperature and air emissions will be predicted. Modifications in design and operation will be optimized.

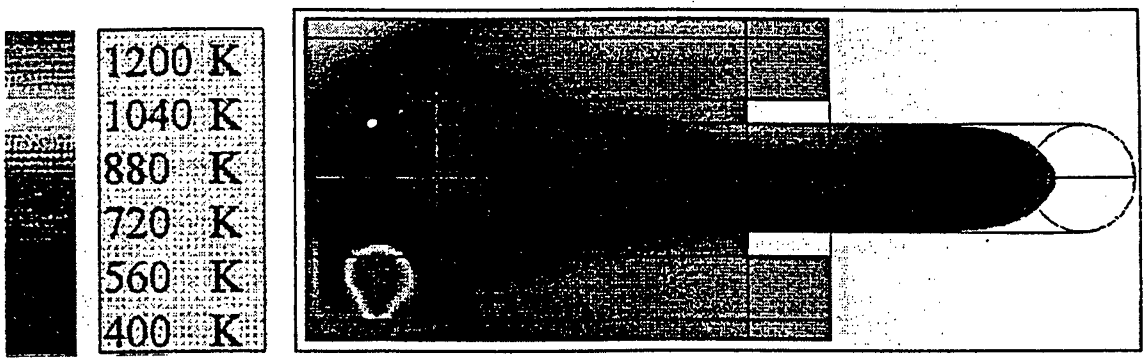

Figure 2 – Temperature Distribution in Vortex Incinerator from CFD Model

These modifications will be validated on the engineering development model in the laboratory. The laboratory is fully instrumented with continuous emission monitoring (CEM) equipment in addition to a high temperature camera to monitor the combustion process. The CEM will monitor for air pollutants and for combustion parameters. These include NOx, SO_2, CO, CO_2, HC, O_2 (wet), O_2 (dry), and opacity. The opacity will be verified with an on-line particle analyzer. The O_2 concentration inside the incinerator will also be monitored.

The engineering development model has been fully instrumented to measure liner temperatures, gas temperatures, gas flows, fuel and liquid waste flows, and gas pressures throughout the incinerator. Data from 40 thermocouples, 6 flowmeters, 8 pressure transducers, and the CEM will be collected real-time with a fully integrated datalogger and control panel.

Potential Advances in Technology

Two technologies offer particular advantage to the upgrade of the existing vortex incinerator. First, O_2 enrichment of the combustion air would increase the effective heating value of the fuel and thus provide more evaporative capacity with less products of combustion. This would reduce exhaust gas volume and thus reduce the probability of increased air emissions.

The second technology is acoustic enhancement of the combustion process. This technology has the potential to also increase the capacity of the vortex incinerator by increasing evaporation and combustion processes (i.e., increasing the heat and mass transfer during the combustion process). Acoustics are used to enhance combustion by generating pressure gradients inside the combustion chamber. These gradients act to increase the surface area of the waste particles, which results in more rapid heat and mass transfer. Therefore, the same combustion process can be achieved in a shorter period of time and, consequently, in a smaller volume. As larger volumes of waste are combusted in the vortex incinerator, more rapid combustion is essential to achieve complete combustion within the same chamber volume. A more complete description of this technology will be provided in another paper.

Conclusion

An integrated approach for the treatment of shipboard non-hazardous liquid waste residues requires a thermal destruction device. Vortex incineration provides an excellent baseline technology for that device. A program to upgrade the existing vortex incinerator for the destruction of treatment residues has started. A capacity increase of 50% appears to be achievable.

<u>Session</u> 3 - Plasma Treatment Technologies

Chairman: Dr. Eugene Nolting,
Naval Surface Warfare Center Carderock Division, USA

Development of a Plasma Arc System for the Destruction of Waste aboard US Navy Warships

Development of a Plasma Arc System for the Destruction of Waste Aboard US Navy Warships

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Introduction:

In 1995, the Naval Surface Warfare Center, Carderock Division (NSWCCD) proposed the development of plasma arc technology for the destruction of shipboard solid waste as part of the Navy's Advanced Technology Demonstration (ATD) Program. The Navy's ATD Program is designed to inject high-risk, high-payoff technologies into the Fleet more quickly than is possible through the conventional research and development cycle. The NSWCCD plasma arc proposal was selected after a highly competitive review process.

Budgetary considerations have now delayed the start of the Plasma Arc ATD, and the future of the R&D program is unknown at the writing of this paper. The goal of the ATD effort is to construct a full-scale, land-based test bed for all the essential elements of a shipboard Plasma Arc Waste Destruction System (PAWDS). This would be followed by a shipboard engineering demonstration ultimately leading to the installation of plasma equipment on new ship construction.

In this paper, the unique Navy mission requirements that drive the design of a shipboard plasma arc waste destruction system are discussed. This is followed by a description of the principle features of the conceptual design developed by the US Navy program during the past two years as preparation for the ATD. Finally, a current status summary of the ongoing work is presented.

Definition of the Shipboard Solid Waste Management Problem:[i]

For the purposes of classification, the Navy categorizes solid waste streams into the following groups: food, paper, cardboard, metals, plastics, textiles, dunnage, glass, wood, aerosols cans, and items of mixed composition. A 1996 statistical analysis of Navy solid waste determined that the composition and quantity of the solid waste generated is related primarily to the ship's population size and is not a strong function of ship class.

Although food waste is the largest component of the solid waste stream by weight with a production rate of 0.55 kg per person per day, it can be pulped and discharged overboard in compliance with Annex V. Since food contains as much as 70% water by weight, there are significant advantages not to thermally process all food waste. However, there is always food contamination on paper, cans, bottles, etc. and non-pulpable matter (e.g. bones and egg shells) that is estimated to represent as much as 10% of the weight of the total food waste. This amount of food matter must be processed as part of the solid waste stream. Plastic waste is currently being treated with Navy Plastic Waste Processors (PWP), which are currently being installed aboard all Navy surface ships. The average generation rate of the remaining non-plastic, non-food, solid-waste is 0.80 kg per person per day.

US Navy studies have shown that there is considerable variation in the generation rates for the different categories of solid waste. Table I lists the mean and standard deviation for the primary solid waste streams of interest. Compared with municipal solid waste, more day-to-day variation occurs in a Navy ship's solid waste. This is partly because of relatively small size of the sample population and partly due to the phasing of the deployment cycle. For example, at the beginning of a deployment there tends to be more fresh food while later there is more use of food contained in metal and glass containers.

TABLE I
Expected Variation in Shipboard Solid Waste Stream Composition

Waste Component	Average Generation Rate (kg/man/day)	Standard Deviation (kg/man/day)
Paper/Cardboard	0.503	0.113
Food (Only 10% of total)	0.054	0.009
Metal (Aluminum/Iron)	0.186	0.045
Glass	0.059	0.014

In order to design a full-scale PAWDS unit with adequate process capacity to treat all the solid waste generated daily under most circumstances, it has been necessary to estimate the size of the waste variations that can reasonably be expected to occur. Assuming that all of the solid waste components can be expressed as statistically independent normal distributions, the maximum daily generation rate (Γ_{max}) for the combined waste streams at a given confidence level is given by the expression

$$\Gamma_{max} = \Sigma\, \mu_i + z_c\, [\Sigma\, \sigma_i^{\,2}]^{1/2}, \tag{1}$$

where μ_i and σ_i are respectively the individual means and standard deviations of the components. The z_c term is a constant dependent upon the confidence level of interest. For a 97.5% confidence level, $z_c = 1.96$. The criteria used is for a single-sided confidence interval, because it is assumed that the only the maximum process rate is the limiting design factor. Table II indicates the waste production for the classes of ships for a notional Mediterranean aircraft carrier battle group based upon the values listed in Table I.

The ATD's basic PAWDS unit design process rate was determined from the waste generation data, the necessity to provide overall system redundancy for reliability, and the desire to have a PAWDS unit size capable of serving as a building block for a variety of ship platforms. A single PAWDS unit designed to treat the maximum amount of waste anticipated was considered too inflexible for treating lower waste production levels and would not provide redundancy of waste treatment capability during periods of maintenance/repair. Two basic deployment options were considered: (1) a single Combat Logistics Support Ship (CLF) that would be tasked to process all the waste generated by the entire battle group, and (2) both a CLF ship and the carrier (or amphibious assault ship) equipped with PAWDS units. In the second scenario, the carrier (or amphibious assault ship) would process its own waste (approximately 70% of the waste produced by the battlegroup) while the support ship would process the waste generated by other elements of the battlegroup. This second approach greatly simplifies the waste treatment process and substantially reduces the amount of time required for underway replenishment and waste collection.

The PAWDS point design unit size has a process rate of 193 kg/hr with an average operating duty cycle of 18 hours per day. Normal operation would be continuous, but an average duty cycle is used to account for repair and maintenance periods. Three of these units can process all the waste produced by a notional Mediterranean Carrier Battle Group approximately 98 out of 100 days. This means that little storage capacity would be required for unprocessed material during the few times the waste production would exceed the processing capability. Two of these units placed on an aircraft carrier would be capable of processing 6940 kg/day, which provides a comfortable margin of excess capacity, see Table II.

TABLE II

Solid Waste Generation Rates in Mediterranean Carrier Battle Group

Number and Class of Ships	Crew Size	Average Waste Production Rate (kg/day)†	95% Confidence Level	
			Minimum (kg/day)	Maximum (kg/day)
1 CVN	6286	5047	3534	6560
2 CG	818*	657	460	854
1 DDG	303	243	170	316
1 CGN	629	504	353	656
2 FFG	440*	353	247	459
1 AOE	630	506	354	658
Total	9106	7310	5118	9508

* Represents the crew total for both ships
† The average production rate of non-food/non-plastic solid waste; includes 10% by weight of food contamination and unpulpable food.

In addition to considering the process rate, the plasma system would have to meet other shipboard imposed requirements. Principal among these is at least a 50% reduction in system size and weight compared with commercially available land-based units. Other specifications include: limited staffing requirements, ship compatibility (i.e. plasma equipment must not cause a personnel safety hazard or interfere with operation of the ship by producing high levels of electromagnetic noise, mechanical noise, or thermal signature), a tolerance for the shipboard environment (e.g. equipment must tolerate shock, vibrations, pitch and roll, etc.), and provide economic destruction of waste. Total prime power for the plasma arc system should be limited to the output capacity of standard Navy shipboard generators, 1.5 MW. To insure stable performance, the power consumption should be no more than about 75% of a generators maximum output (1.1 MW). Furthermore, the electrical power system must comply with the ship's standard grounding procedures to ensure personnel safety and electrical noise suppression. These stipulations dictated the evolution of system design described in the next section.

A primary goal of the ATD is to develop a plasma arc unit capable of processing the waste generated by an entire battle group in a total system volume of 283 m^3 and a total system weight of 32 metric tons; this is approximately half the size and weight of commercial units with the same throughput capacity. Space onboard warships is always a premium, on the larger vessels weight is less of a restriction. In general, the more compact and lightweight that a system can be made the more acceptable it will be for ship installation. Reducing the system size while maintaining the throughput significantly increases the power density which increases the emphasis on good thermal management and material selection.

Metal and glass comprise approximately 30% (by weight) of the nominal shipboard solid waste stream which results in a process rate of 72 kg/hr (including the inorganic filler in white paper and nonpulpable food). If the iron and aluminum are fully oxidized, the mass additional oxygen increases the hourly slag production to approximately 97 kg/hr. Oxidation of the metals substantially increases the processed product weight over that of the raw waste material. Our research has shown that the use of an oxidizing environment, when both aluminum and iron waste are treated with less than about 3% by weight glass present, can cause a highly energetic, thermite reaction to occur[ii]. A thermite reaction can cause rapid boiling and splattering of the molten material; it also can create localized cracking of refractories. In addition, if the aluminum is fully oxidized without sufficient glass or other fluxing agent present, then a much higher melting temperature slag is formed that would be difficult to remove from the cooling chamber. Oxidized molten iron also exhibits a corrosive effect on high alumina refractory liners.[iii] However, if heavy metals are present, an unoxidized metal slag would not be expected to pass the Toxicity Characteristics Leaching Procedure (TCLP) test. It should be noted that in the future glass may no longer be present aboard Navy warships; the choice of the best procedures to follow for the treatment of the inorganic waste stream will be critical. It is one of the advantages of the PAWDS design that a variety of thermal processing options are possible.

Although an adequate supply of sea water exists that can be used for cooling, there is generally a lack of fresh water on most warships. Aircraft carriers are the exception; new-membrane separators could be developed to provide up to 1200 m^3/day of non-potable fresh water. This water could be used for single pass cooling and rapid quench of the offgases (typically on the order of 12 liters/minute/unit) to prevent the production of complex organic molecules (e.g. dioxins and furans). Other classes of ships would have to use saltwater heat exchangers to provide cooling.

System availability, reliability and maintainability are critical elements of the shipboard design. The ATD test plans require recording data to allow the estimation of the reliability for a shipboard system. A goal of the ATD program is to produce a unit that, excluding torch life, has a mean time between critical failure exceeding 400 operating hours. Ideally, a shipboard system would only require major maintenance shore-side. A critical failure is an occurrence which terminates the operation of the PAWDS. Minor repairs, such as electrode replacement, are defined as those requiring less than four hours to accomplish; critical repairs are those that necessitate a down time of twelve hours or more. A complete overhaul of the equipment should be required only during Service Life Extension Program (SLEP) repairs, or about every ten years.

PAWDS Baseline Design Overview

For any thermal treatment process a primary consideration is the variability of the waste stream. As described above, the waste can vary both in composition and amount; furthermore the water content of the organic material can be expected to range from about 5% to 70%. The base line PAWDS design minimizes the fluctuations in the waste feed so that a stable near-optimum operating point can be achieved. By reducing these variations there is much less dependency on automated sensor/control systems or human controllers to insure proper waste destruction. This is achieved by the use of two separate primary processing chambers, one for organic wastes (paper, food, wood, cardboard, textiles, etc.) and the other for inorganic wastes (iron, aluminum and glass). There are three important advantages associated with the separation of the waste streams. First, the complexity of competing chemical kinetic processes between the processing of organic and inorganic wastes is eliminated. Second, slag handling becomes simpler. Finally, the separation of wastes increases the system flexibility, for example, it may be desirable for some ships to have one inorganic processor with two organic units.

The principal element of the organic waste destruction system is the plasma eductor, shown in Figure 1 (US Patent Applied for). Food and paper wastes are preprocessed close to the point of generation with the use of existing Navy pulpers. After pulping, the material is transported as a slurry to the location of the PAWDS unit; this procedure minimizes manpower associated with handling the trash aboard the ship. At the PAWDS site, the pulp slurry is mechanically de-watered to concentrate it into about 50% solid content by weight. After de-watering, the pulped material is dried, using rejected heat from the waste combustion process, and pulverized into small diameter particles (estimated $\leq$ 500 μm). These small particles are then pneumatically transported to the injector/plasma eductor assembly where they are brought directly in contact with the ultra-high temperature ($\geq$ 5000 °C) plasma flame. The combination of small particle size and direct mixing with the plasma torch gas greatly reduces the time that it takes to raise the waste to gasification temperatures.[iv] Computational fluid dynamic models based upon measured, high-temperature kinetic reaction rate data indicate that the pulp is completely gasified by the time it transits the plasma eductor assembly. After the waste is transformed into fuel gases, sufficient air or oxygen-enhanced air is provided to achieve full combustion (creating primarily CO_2 and H_2O) in a secondary chamber. Calculations suggest that a secondary chamber may not even be required if sufficient air is added to the diffuser section of the eductor. This is because the faster reaction rates at higher temperatures, the small particle size and enhanced mixing caused by the eductor geometry greatly reduce the time for full combustion to occur. Despite the high temperatures and the presence of nitrogen in the air, it has been found both experimentally and theoretically that NOX formation is suppressed due to the greater affinity of oxygen for hydrocarbon spiecies.[v] Other components of the organic waste stream (cardboard boxes, plastic coated cardboard, wood from dunnage and pallets, etc.) enter the process system via stations conveniently sited around the ship. Here the material is shredded and pneumatically transported to the PAWDS site, pulverized and dried before injection into the plasma eductor.

There are two conceptual designs currently being considered for the inorganic waste stream. In the first shown in Figure 2, a small chamber lined with Ruby™ (Harbison-Walker Refractories) refractory or other non-iron-oxide-soluble refractory is used to contain the molten shredded metal/glass waste. The size of the chamber is chosen to be small so that only a small amount of molten material (approximately 4 liters) is present at anytime. While the waste is fed in a continuous batch mode, the non-transferred torch flame is moved around the chamber interior to thoroughly heat and melt all the material. The molten material lies at the bottom of the relatively steep walled container to minimize the effect of ship motion (up to $\pm$ 15° roll and $\pm$ 30° pitch). At the very bottom of the chamber, the molten material freezes and forms a skull over the small diameter (about 1 cm) drain pipe which seals the slag inside the chamber. When melting of the batch is complete, an induction heat source is actuated to heat the solidified slag to a liquid state allowing drainage of the chamber to occur. The pour is limited to 18 kg in order to meet US Navy Occupational Safety and Health (NAVOSH) standards which restricts the amount of weight lifted by personnel to this value. For a pure iron slag, this is a three liter pour. The three liters of molten material is poured into a water-cooled mold that forms an approximate 2.5 cm thick by 39 cm diameter disk. This disk geometry enhances the cooling rate so that the slag solidifies rapidly and is ready for disposal in about 15 minutes. The weight of the disk will depend on the composition of the material; the nominal waste stream density is 4.7 gm/cm^3. A 18 kg disk with this density would be slightly more than 3 cm thick. Approximately four pourings per hour would be required to process the nominal 72 kg/hr designed processing rate.

The advantages of this design are: (1) it is similar to commercially available plasma treatment units, (2) if desired the aluminum, iron and glass can be segregated for recycling, (3) the cooled disks are easily stored, (4) the chamber can also be used for small amounts of mixed organic/inorganic materials (such as medical wastes) which cannot be safely shredded and put in the organic feed, and (5) the option to fully oxidize the product to form a vitrified solid to encapsulate heavy metals is possible. The disadvantages are that there is a small, but finite molten pool, and refractory materials are used which increases size and weight as well as system vulnerability to shock and vibration.

The second inorganic plasma processing system concept would inject finely divided inorganic materials into a plasma eductor like configuration. It might be possible to develop a single eductor geometry for both the inorganic and organic waste steams. However, the optimum geometry for the inogranic processing eductor may be different from the organic design. The optimum configuration will be determined through theoretical and experimental studies. In this concept, the small, inorganic particles would undergo melting as they pass through the plasma torch flame, the molten material would then be splat-cooled upon contact with a water-cooled mold located near the output end of the eductor. For the nominal 1.2 kg/min. (72 kg/hr) feed rate approximately 30 kW of thermal power is required to bring the waste stream to melt. Because of the small particle size, a relatively high percentage of the iron should be oxidized when air is used as the torch gas, but the concern of a thermite reaction is minimal due to the small amount of molten material present at any one instant in time. Once the water-cooled mold is filled, the feed would be shut off momentarily until the plasma spray molded material was removed and the next water-cooled form could be put in place.

Advantages of this approach are: (1) very little molten material is present, (2) no significant thermite reaction can occur, (3) process is independent of inorganic waste composition, (4) no refractory liners are required, (5) unaffected by ship motion, and (6) system should be instant on/off. The disadvantages are: (1) the inorganic waste will have to undergo sufficient preprocessing so that complete melting is assured during the waste's passage through the plasma eductor, (2) the torch flame will require high enthalpy in order to insure complete melting of all the material which results in a lower efficiency, (3) the inorganic eductor will be limited to a vertical orientation, (4) off gas handling will be more complex particularly if sizable amounts of organic waste (e.g. paper labels) are mixed with the inorganic waste stream, and (5) a PAWDS unit with only an eductor geometry may not be optimum for treating some waste streams (e.g. medical waste).

Summary/Status

The US Navy has looked extensively at various shipboard solid waste management methods and has concluded that ultra-high temperature plasma systems have the best potential of treating all the major solid waste streams. However, the US Navy also found that the currently available land-based systems would require considerable modification before the plasma technology could be used aboard warships. For these reasons, in 1995 NSWCCD proposed the construction of a shipboard-configured, land-based plasma system that would demonstrate all the key technologies required. A R&D effort was initiated to reduce the risk to the ATD program by developing some of the basic concepts. As part of this activity a conceptual design for a shipboard system was developed that addresses many of the technical issues associated with a plasma system shipboard deployment.

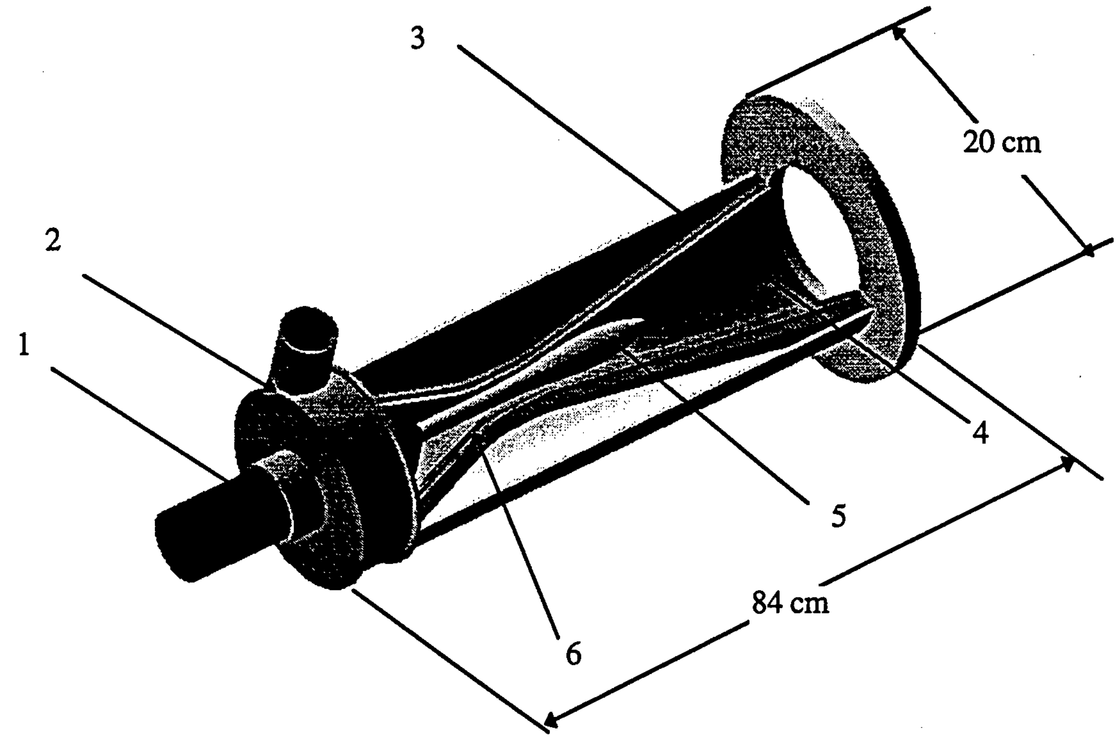


Figure 1. Drawing showing configuration of the plasma eductor assembly. (1) Non-transferred plasma torch, (2) waste particle injector assembly, (3) water-jacket (4) plasma eductor diffuser section, (5) palsma plume, and (6) high temperature insulating layer.

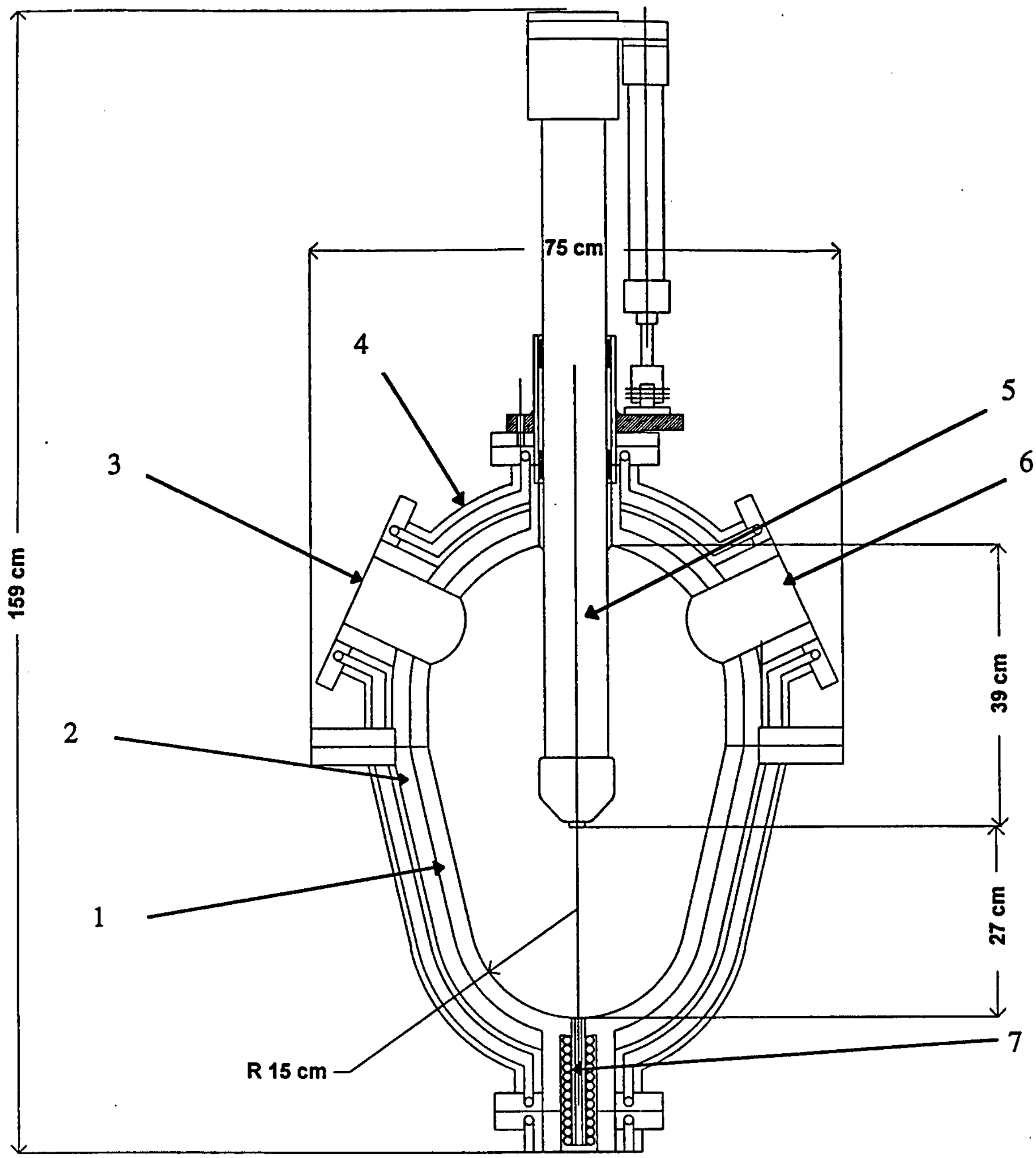


Figure 2 Configuration of the metal/glass processor (1) Ruby™ working refractory, (2) insulating refractor (3) waste feed port, (4) housing/water-jacket, (5) non-transferred plasma torch, (6) off gas vent, and (7) inductively heated valve.

References

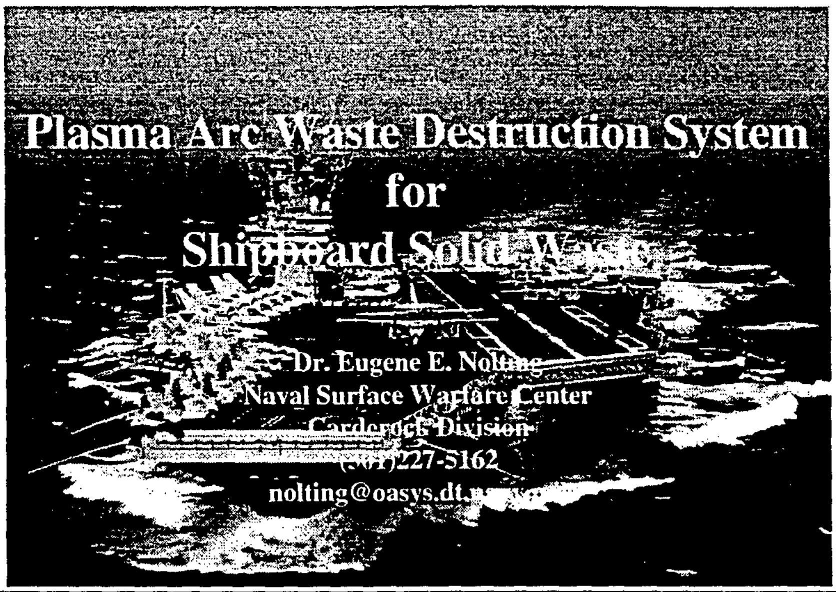
[i] Information in this section is more fully described in E. Nolting, et. al. "Navy Shipboard Plasma Arc System Development Program", Proceedings of 1997 International Conference of Incineration and Thermal Treatment Technologies, University of California at Irvine, p 553.

[ii] I. G. Talmy, et. al., "Occurrence and Suppression of Thermite Reaction in Slags from Destruction of Navy Shipboard Wastes", Proceedings of 1997 International Conference of Incineration and Thermal Treatment Technologies, University of California at Irvine, p 621.

[iii] S. Peterson, et. al., "Slag Formation from Navy Solid Waste with a Plasma Arc Torch Destruction System", Proceedings of 1997 International Conference of Incineration and Thermal Treatment Technologies, University of California at Irvine, p 101.

[iv] A. Gupta, et. al., "An Investigation on the Pyrolysis of Cellulose and Surrogate Solid Waste", Proceedings of 1997 International Conference of Incineration and Thermal Treatment Technologies, University of California at Irvine, p 337.

[v] H.Uhm, et, al., "Air Torch Modeling for Thermal Destruction", Proceedings of 1997 International Conference of Incineration and Thermal Treatment Technologies, University of California at Irvine, p 795.


Plasma Arc Waste Destruction System
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Acknowledgments

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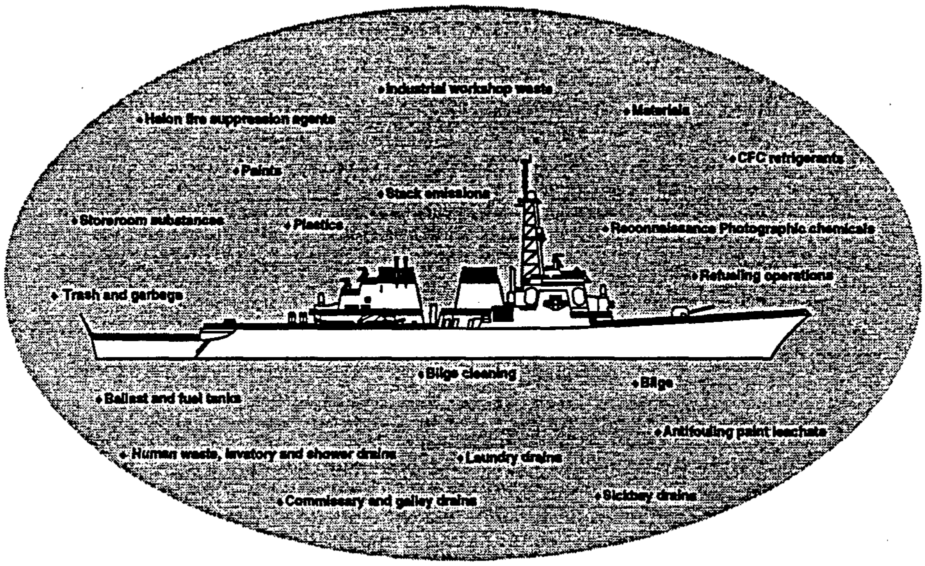
The Plasma Arc Waste Destruction System (PAWDS) Working Group members have been responsible for the development of the shipboard concept design which will be discussed in this presentation.

Variety of Shipboard Waste Streams



Like small cities US Navy ships produce a variety of wastes which can no longer be routinely discharged overboard. A waste processor capable of destroying all the waste in an environmentally acceptable way would be ideal. While this may never be practical in practice, there is significant value in developing an integrated waste management system that can treat a large variety of waste streams.

Plasma as a Solution to Navy Shipboard Waste

- After several studies the Navy has concluded that plasma arc technology is the best candidate for achieving an integrated shipboard waste processing system
- Those same studies indicated that the commercially available plasma systems are currently unsuitable for shipboard installation and operation
- In FY95, NSWCCD proposed land-based demonstration effort to fill the technology gaps identified
  - Originally scheduled to begin in FY97, but postponed FY98 due to budget cuts
  - FY98 funding cuts have delayed the program indefinitely
- The following describes some of the work which has been performed to support the planned start up of the program

Over a period of several years, the US Navy has investigated many technological approaches to shipboard waste management. Several of these studies have concluded that because of their ultra-high operating temperatures plasma arc systems have the best potential for being the basis of an integrated thermal destruction system. However, the same studies have found that commercially available plasma units are not suitable for shipboard operation. As a result of this finding, the Naval Surface Warfare Center Carderock Division (NSWCCD) proposed a major R&D effort in FY95 as part of the Navy's Advanced Technology Demonstration (ATD) Program. The ATD program is designed to take high-risk, high pay-off technologies and develop them for rapid insertion into the Fleet. The NSWCCD proposal was designed to address all the major technologies issues associated with shipboard plasma arc operation. To reach this objective, the ATD proposal was to build a full-scale, land-based pre-prototypical unit and demonstrate its performance characteristics. The NSWCCD proposal was widely supported by the operational Navy and was chosen to begin in FY97.

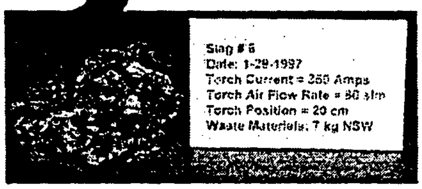
In FY97, funding cuts delayed the program from starting as planned and a smaller R&D effort was continued in anticipation of an FY98 start. This program is currently unfunded because of overall budget cuts in the ATD funding for FY98.

PAWDS can Significantly Reduce Volume of Onboard Waste

- Navy warships are not designed to store trash
- Over $100M spent annually for disposal of US Navy solid/liquid waste
- Large (≥ 75:1) waste volume reduction
  - Complete destruction of organic waste and densification of inorganic waste
- Reduce volume of off-gas as much as 3:1 versus incineration
- Will enable full compliance with MARPOL Annex V

Integrated approach to shipboard waste management

Ten days solid waste USNS Big Horn, T-AO 198



Slag formed from Navy Solid Waste

A principle goal of the ATD program was to develop a full-scale, land-based pre-prototypical design for the destruction of Navy solid waste (primarily paper, cardboard, food contaminated paper and cardboard, metal cans and glass containers). The plan also required that the ATD plasma hardware would be used to determine the effectiveness of the plasma technology to thermally destroy concentrated liquid waste streams.

PAWDS Ship Impact

- PAWDS has potential for broad shipboard impact
  - Environmental compliance: Fully comply with MARPOL Annex V
  - Manning: Reduce manpower required for ship waste management
  - Improved quality of life
    - Safety
    - Health
  - Affordability: Lower in port waste disposal cost
  - Fire:Reduce fire hazard from stored combustible waste
  - Compatible with all electric ship design

While the purpose of the shipboard plasma system is intended to allow the US Navy fully comply with the MARPOL Annex V, the system will impact a number of shipboard areas.

PAWDS R&D Program Objectives

- **Plasma arc technology is not new**
  - **Over 90 years of commercial applications: e.g. metal processing, fertilizer and acetylene production, mixed waste (nuclear and hazardous) treatment**
- **The challenge is to adapt the technology for use aboard warships**
  - **Major technical issues to be resolved**
    - **Size and weight reduction (minimum of 50%)**
    - **Simplify operation-Reduced manpower**
    - **Platform motion**
    - **Waste stream variability**
    - **Operational requirements: reliability, maintainability, operability**
    - **Environmental requirements: shock, vibration, noise, EMI, etc.**
    - **Fast start up/shut down**
  - **Addressing these issues requires fundamental S&T advancements in the technology**

The use of plasma arcs for a variety of industrial -like applications is not new. For well over ninety years plasma arc technology has been used for applications such as high purity metal processing, and fertilizer and acetylene production. More recently the Department of Energy has invested well over $100M in developing the PAT for the disposal of mixed (radioactive and hazardous wasts). There are several companies which have medical waste destruction systems as one of their product lines.

The problem as we see it is not whether the plasma arc technology can be used to destroy the waste generated aboard ships, but whether it can be adapted for shipboard use. There are several issues that must be resolved before the answer can be stated in the affirmative. For example, building a unit with equal or increased processing capacity (compared with commercially available units) while reducing the size and weight requires significant increases in power density. This increased power density raises a number of material questions. We believe to successfully address these issues requires fundamental science and technology advancements. Furthermore, the solutions to the technical questions must also be consistent with the constraints imposed by the warship environment. Because they have had a commercially viable product, the commercial plasma companies have had little incentive to address these issues.

Daily Non-Food Solid Waste Generation Rates

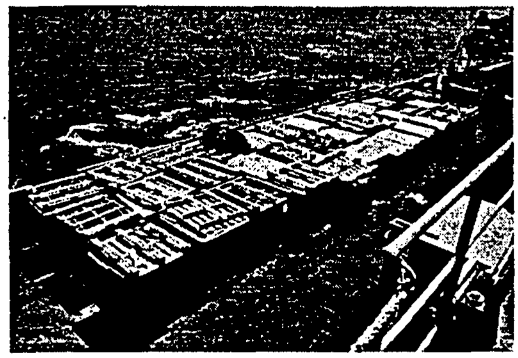
CVN Battle Group PAWDS

#/class of ships	Crew size	lb/day	cuft/day
1 CVN	6,286	11,126	1,494
2 CG*	818	1,448	194
1 DDG	303	536	72
1 CGN	629	1,113	149
2 FFG*	440	779	105
1 AOE	630	1,115	150
Total	9,106	16,118	2,164

Solid waste includes 10% food contamination and no plastics

* Crew size for both ships

Photograph of daily CVN solid waste generation
(Uncompacted, non-food, non plastic waste)



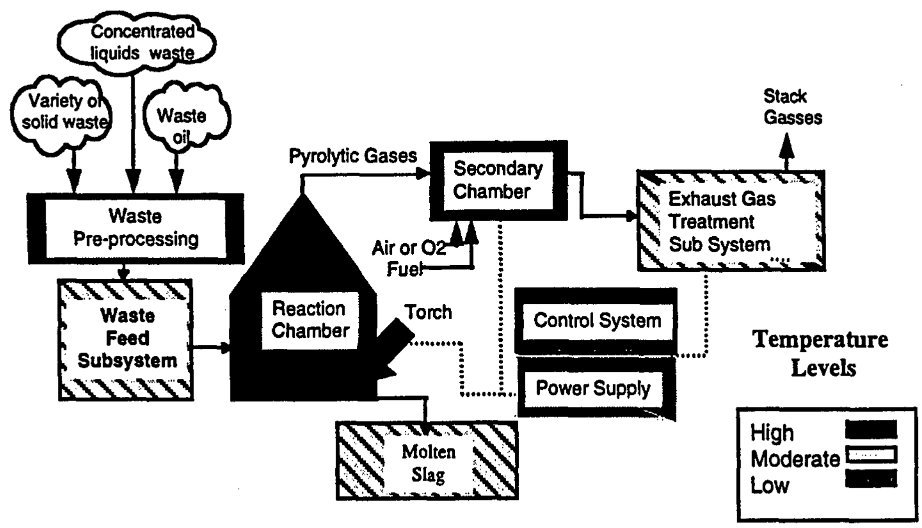
Carrier Based PAWDS

Ship	Crew	lb/day	cuft/day
1 CVN	6,286	11,126	1,494

Ref: Navy Solid and Plastic Waste Management Plan, April 1993

The magnitude of the shipboard solid waste problem is shown in the photograph. This represents the approximate volume of non-compacted solid waste generated daily aboard an aircraft carrier. Each of the Triwall boxes hold about 44 cubic ft (1.25 m^3). Warships, even aircraft carriers, do not have space to store this amount of waste without seriously impacting shipboard operations.

General PAWDS Process



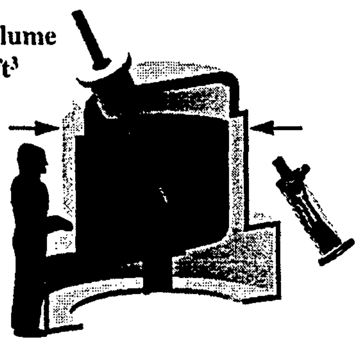
This is a diagram of a generic plasma arc waste destruction system. Although specific details may be different for a given design, most will contain these basic elements. From where the waste originates, it is usually preprocessed (may just be placed in a bag) and transported to PAWDS site. From there it is transferred from room temperature to the interior of the primary reaction chamber which is operated at high temperatures (typically 1500 °C and above). In the primary chamber, organic material is gasified (forming primarily CO and H) and vented to a secondary chamber where it is burned to form mostly CO_2 and H_2O. From the secondary chamber the exhaust gases are sent to the off-gas treatment system prior to their re-enter into the environment. Inorganic waste in the primary chamber is turned to a molten slag which is transferred to a final collection subsystem for final disposition. The operation of each of these subsystems has been considered in the NSWCCD shipboard concept design.

PAWDS Shipboard Design Concept

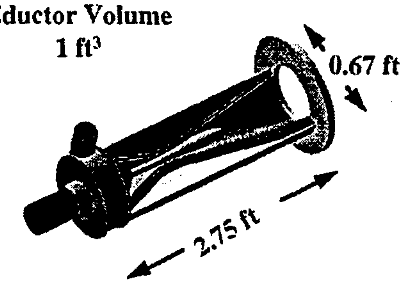
- ❑ Maximize interaction of waste with high temperature torch gas to maximize destruction rates
- ❑ Segregated waste streams minimize variations in thermal destruction chemistry
- ❑ Waste transport designed to limit manpower requirements
- ❑ Cold wall design to reduce volume and weight
- ❑ Cold wall design to limit start-up and cool-down times
- ❑ Minimize the amount of molten material present
- ❑ Solid residue weight limited to Navy Occupational Health and Safety Standards
- ❑ Use of "clean water" permeate to pulp and quench exhaust gas to limit chlorine content
- ❑ Rapid quench with rotary scrubber with underwater discharge

The NSWCCD shipboard PAWDS conceptual design contains several features not typically found in commercially available units. These features were all included because of specific ship constraints and operational requirements.

Plasma Eductor Size Comparison with PCF Primary Chamber



Plasma Centrifugal Furnace/
Plasma Eductor (To Scale)

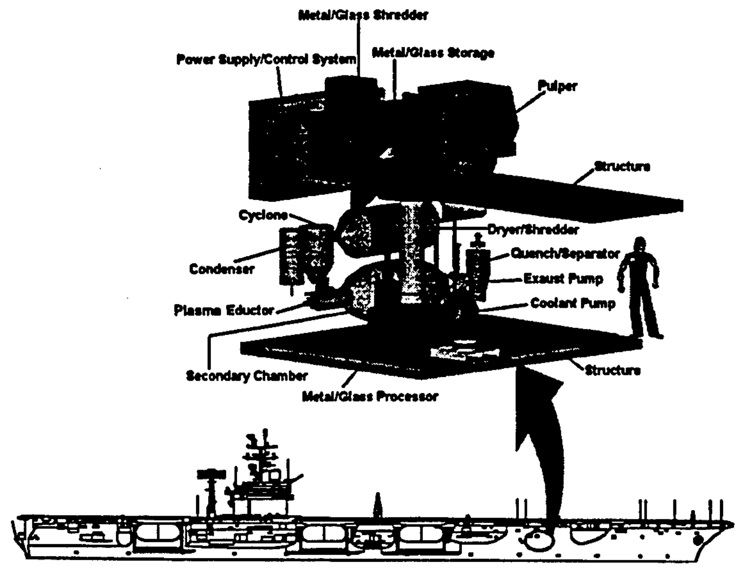


Plasma Eductor

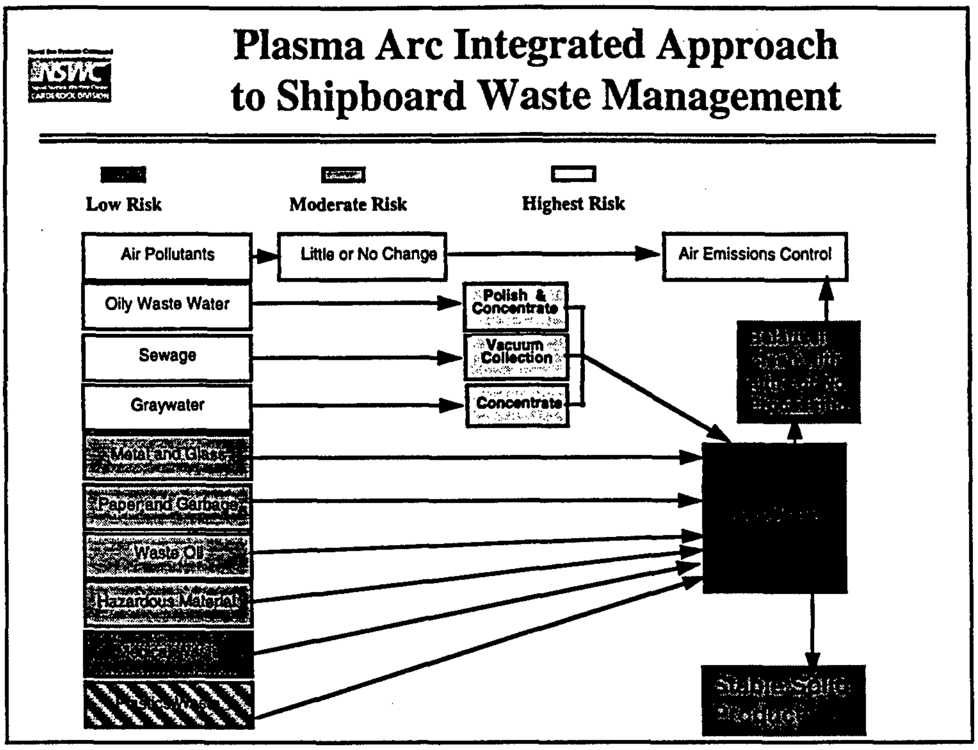
One of largest and heaviest subsystems of a PAWDS is the primary chamber. These are typically lined with thick wall refractories to protect and insulate the chamber's metal walls. Commercially available systems are usually designed for high inorganic content waste and ordinarily collect hundreds or thousands of pounds of molten slag prior to transferring the material to the slag handling system.

In the NSWCCD conceptual design, organic waste (approximately 90% by volume of shipboard waste) is separated from the inorganic waste at the source. In the mess areas, the paper and cardboard would be pulped (ideally with potable permeate from shipboard waste water concentrators) and slurried to the PAWDS site. Here the water is extracted and the pulp is dried and pulverized for injection into the PAWDS plasma eductor. Paper, cardboard and wood generated in other areas of the ship would undergo shredding at multiple sites around the ship and then be pneumatically transported to the PAWDS where it is merged with the the slurried waste prior to grinding. The small diameter, pre-processed pulp limits the time required for the conduction of thermal energy through the body. This causes the material to achieve gasification temperatures in a few milliseconds, which allows the design of a compact system. In the plasma eductor the waste particles are mixed directly with the hot torch gases to maximize the destruction rates. The plasma eductor shown is designed to process paper, cardboard and wood at a rate of 300 lbs/ hour. Two of these units would have enough capacity to process all the paper and cardboard waste generated on an aircraft carrier in an 18 hour day 97.5% of the time.

Shipboard *PAWDS* Layout



A conceptual design of a PAWDS system. Although there are pulpers and shredders shown above the organic and inorganic plasma units, they would probably be best located at several sites around the ship for pre-processing prior to the transport of waste to the PAWDS site.

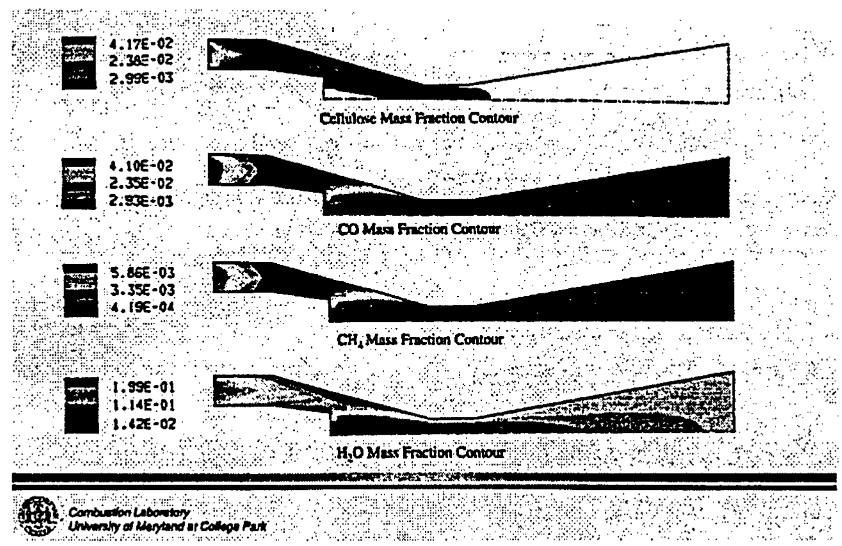


During recent discussions with the aircraft carrier program office, they have indicated that they would want a thermal destruction system to process as many of the ship generated waste streams as possible. This diagram indicates that broadening of the waste stream.

The US Navy has plans to remove chlorinated plastics from its ships which helps in simplifying the thermal chemistry. Plastics add heat value to the waste stream so that their introduction will not require increased torch power; however, designing a system that will finely grind all types of plastic waste for introduction into the plasma eductor may be a technical challenge. Waste oil could also be sprayed into the eductor.

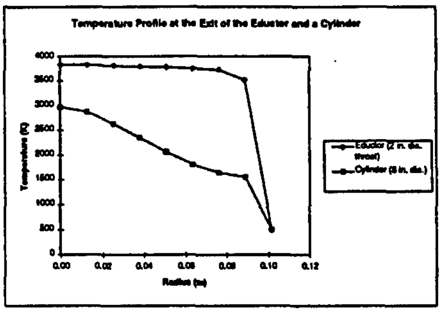
Medical waste and hazardous materials would have to be delivered directly to the PAWDS site and fed into the inorganic unit to avoid the possibilty of contamination.

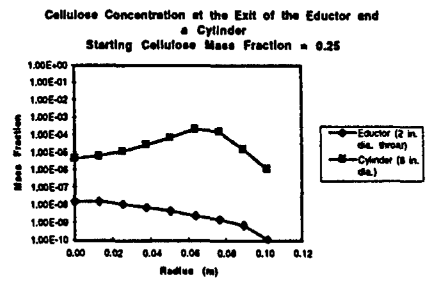
Species Distribution in the Plasma Eductor $(T_{wall}=500\ K)$



These are some of results from the University of Maryland's Computational Fluid Dynamic (CFD) code analyses of the plasma eductor. The upper figure shows that cellulose tends to be completely gasified by the time it reaches the diffuser section of the nozzle. This calculation was for 50% stochiometric air. The results indicate that their may be some hope of extending the diffuser section length and introduce sufficient air to have the plasma eductor act as both a primary and secondary chamber.

Effect of Geometry on Processing





Source: CFD calculations by the Combustion Laboratory at the University of Maryland

Further results of the CFD calculations. These curves indicate the effect of the eductor nozzle geometry compared with a simple cylindrical geometry. Note, there is a three to four order of magnitude reduction in the amount of cellulose reaching the exit with the eductor geometry when compared with a straight cylinder.

Shipboard Requirements

The goal is to develop plasma technology for installation on Navy warships, not to develop warships to accept the plasma technology

- **Although Navy ships are large, on board spaces are allocated for mission-related functions**
  - **Reduction of volume and weight are critical ATD objectives**
    - **≤ 10,000 ft^3 (283 m^3)**
    - **≤ 70,000 lbs (32 metric tons)**
- **Manpower reduction is a top Navy priority**
  - **System must not increase ships crew size, should reduce manpower**
  - **Minimize training requirements**
- **Reliability, operability, maintainability are important considerations**
  - **Minimum MTBR ≥ 250 hours**
  - **Rapid turn-around on routine maintenance**
- **Process must tolerate relatively large variations in waste stream**

Additional Shipboard Requirements

- Electrical power requirements should be matched to Navy generators 1.5 MW
- System must be compatible with rapid start up and shut down
- Safety of personnel and ship equipment primary concern
- Availability of fresh water can be limited on certain ship classes
- Must meet Navy unique requirements of electromagnetic compatibility, Grade B shock certification, vibration and acoustic noise
- Platform motion
  - Operate without degradation ±15° pitch and roll
  - No damage from ±30° pitch and roll
- Off-gas temperatures ≤ 232 °C (450 °F)
- MTBCF ≥ 400 hours excluding torch electrodes

Navy Plasma Arc Papers

- Related papers presented at the 1997 Conference on Incineration and Thermal Treatment Technologies {Copies available upon request}
  - E. E. Nolting et. al, "Navy Shipboard Plasma Arc System Development Program"
  - R. V. Richard et. al., "Navy Shipboard Plasma Arc Waste Destruction System (PAWDS) Baseline Conceptual Design"
  - S. H. Peterson, et. al., "Slag Formation form Navy Solid Waste with a Plasma Arc Torch Destruction System"
  - A. K. Gupta, et. al. "An Investigation on the Pyrolysis of Cellulose and Surrogate Solid Waste"
  - I. Talmy et. al., "Occurrence and Suppression of Thermite Reaction in Slags from Destruction of Navy Shipboard Wastes"
  - H. S. Uhm, et. al., "Air and Steam Torch Modeling for Thermal Destruction"

Session 3 - Plasma Treatment Technologies

Plasma Devices for Use in Effluent Gas Clean-up

by Dr. Norman Jorgensen,
AEA Technology, United Kingdom

Plasma Devices for Use in Effluent Gas Clean-up

Dr Norman Jorgensen

Environmental Systems & Services, AEA Technology,
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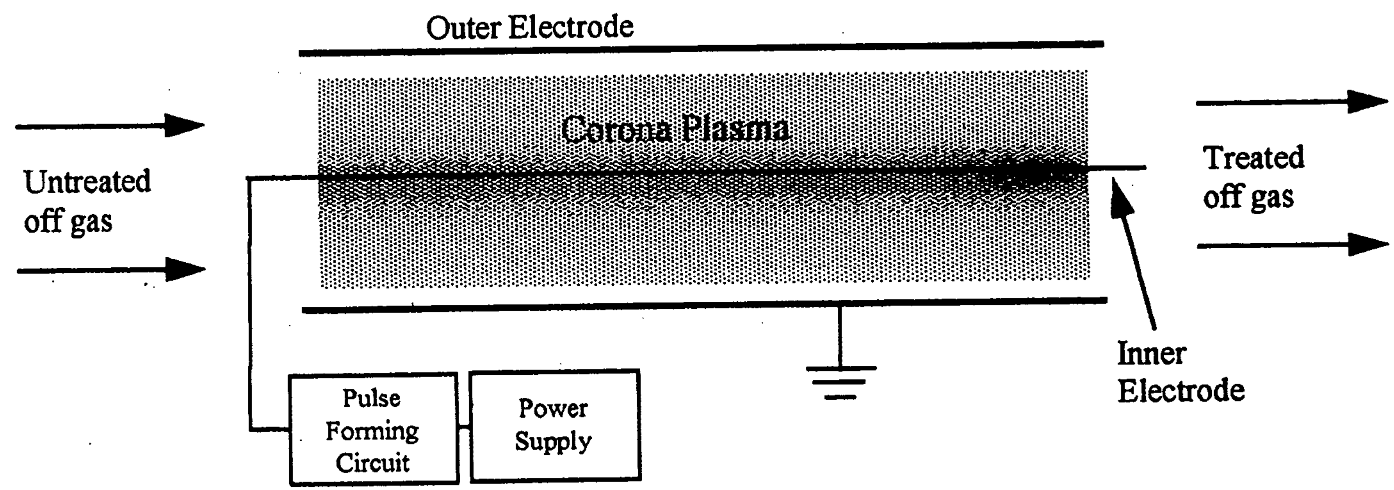
AEA Technology

Slide serial no 3

What is pulsed corona?

- Electrical breakdown of gas using high voltage pulses to create plasma streamers
- Chemically reactive species created by the plasma destroy the pollutants



AEA Technology

Slide serial no 1

Why pulsed corona?

- Pulsed corona plasma is "non-thermal"
- Plasma energy in the electrons not in ions or atoms/molecules
- Electrons create chemically active species which destroy pollutants
  - reactively hot
  - thermally cool
  - energy efficient (waste heat minimised)
- Will destroy many species (Dioxins, NOx, VOCs, SOx)

3

AEA Technology

By products

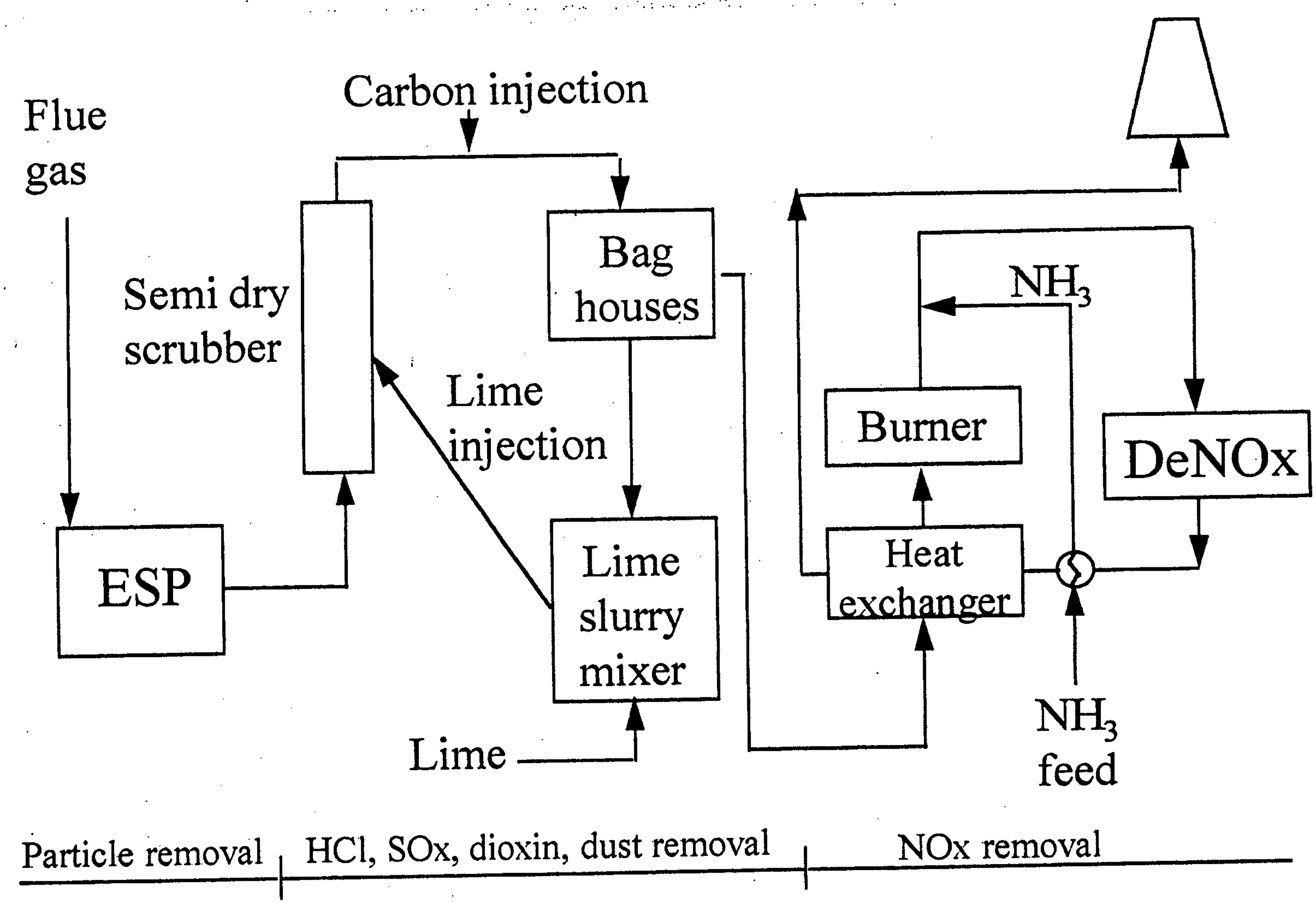
- NOx, SOx $\longrightarrow$ acids
  - remove by scrubbing

- VOCs (Volatile Organic Compounds)

  $\longrightarrow$ CO_2 and H_2O

AEA Technology

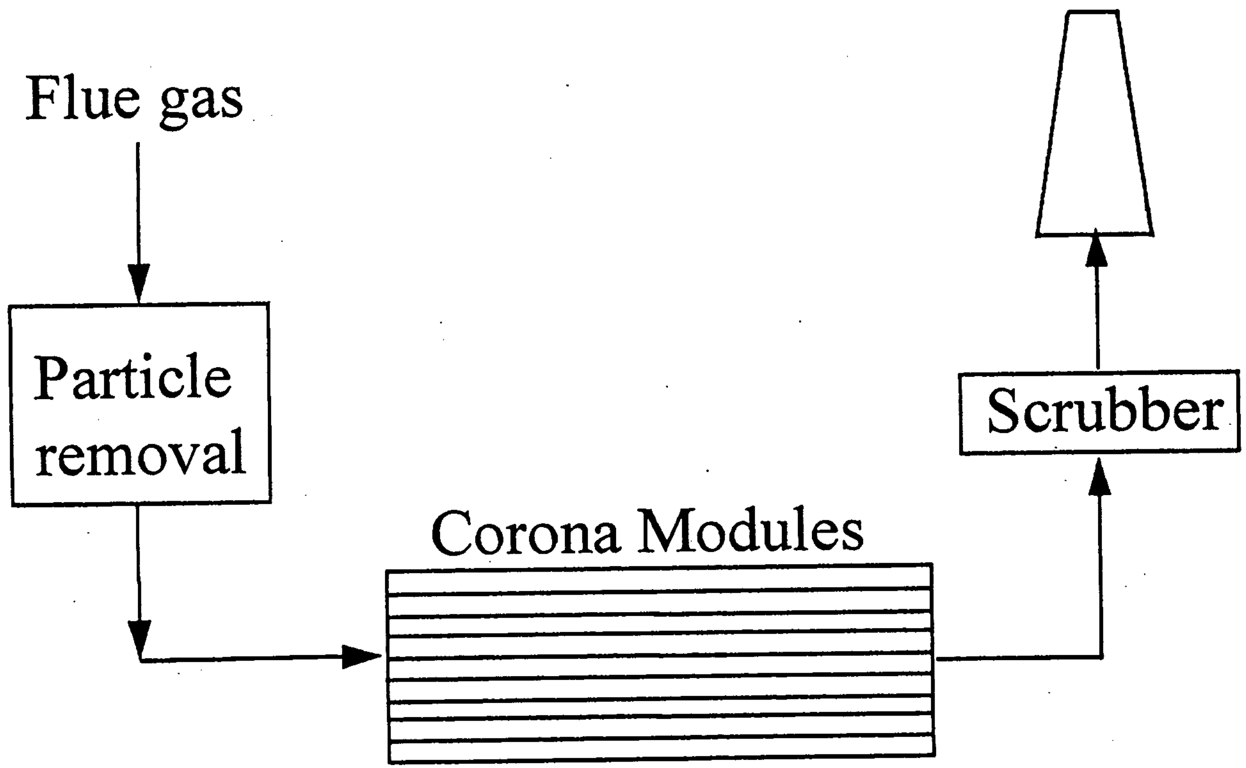
Slide serial no 10



AEA Technology

Slide serial no 4

Need for many abatement systems eliminated or greatly reduced



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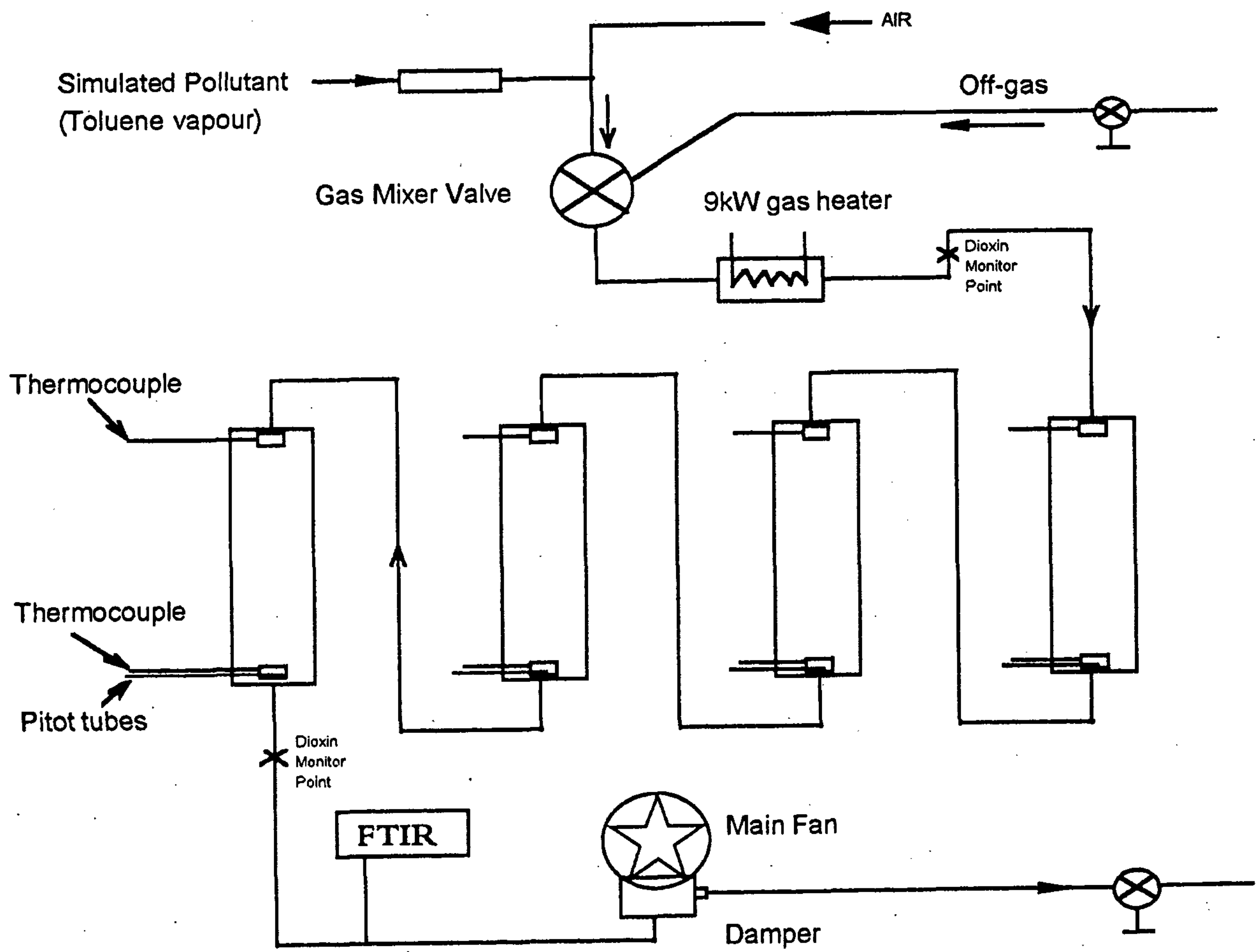

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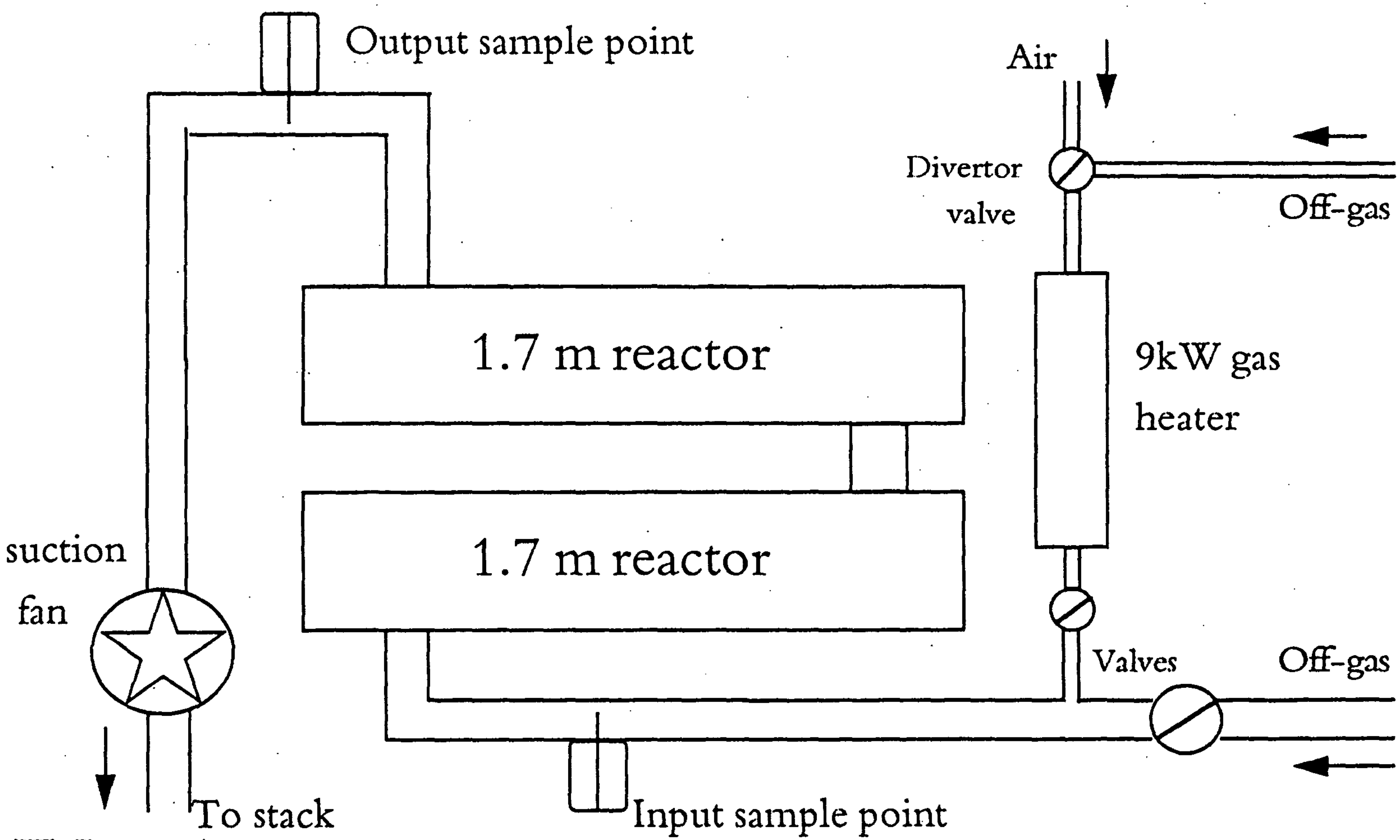
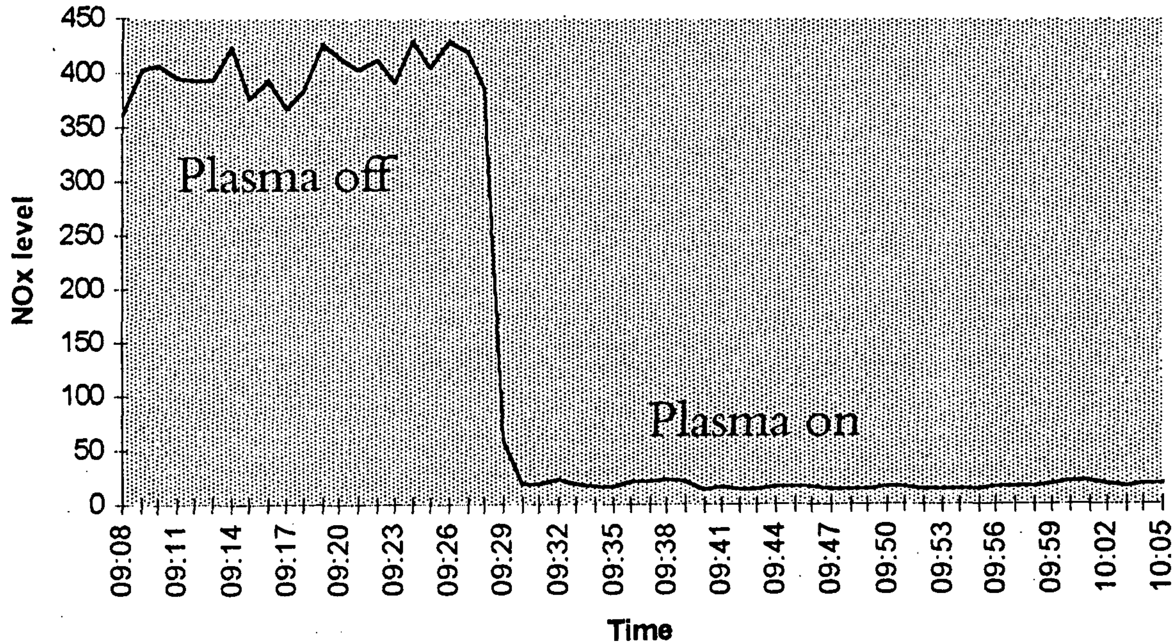


AEA Technology

Slide serial no 11

NO_x test results at $60m^3/hr$ at Chineham Incinerator (NOx levels in mg Nm^{-3})



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Destruction efficiency is measured by the specific energy to achieve a required destruction percentage

Specific energy = Watt hours/m^3

Required power = Specific energy x flow

Specific energy depends on:

- species (some molecules are harder to destroy than others)
- concentration (the energy input is shared between the number of molecules present)

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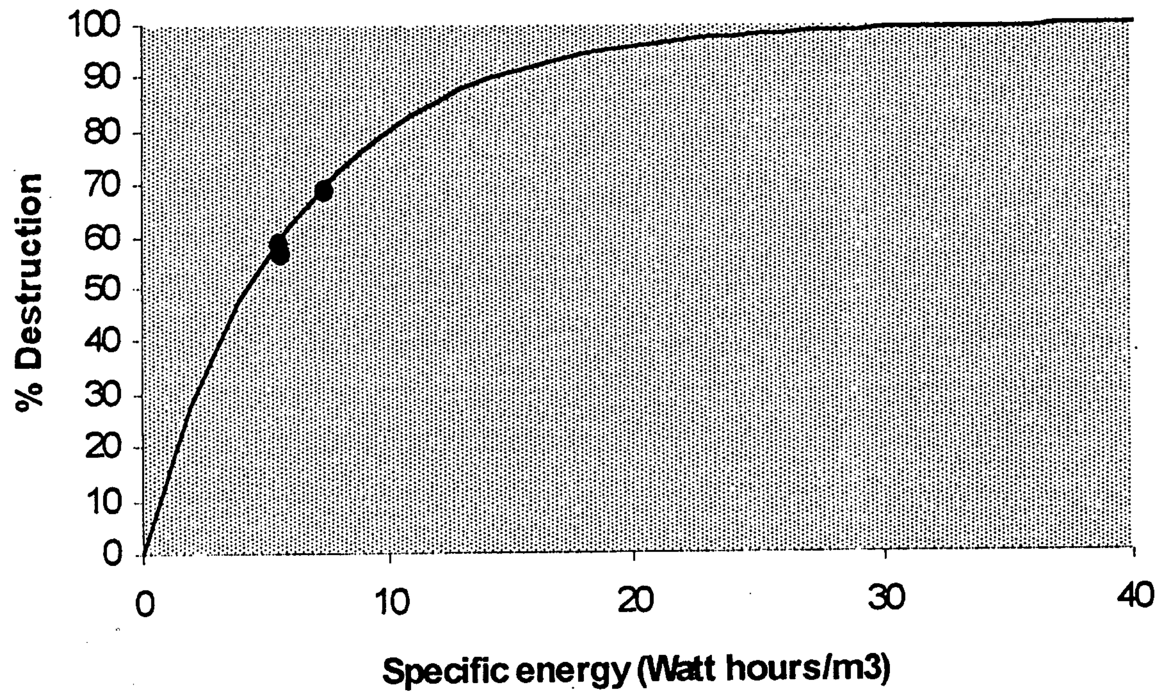
Slide serial no 12

NOx destruction for flows between 250 and 960 m3/hr



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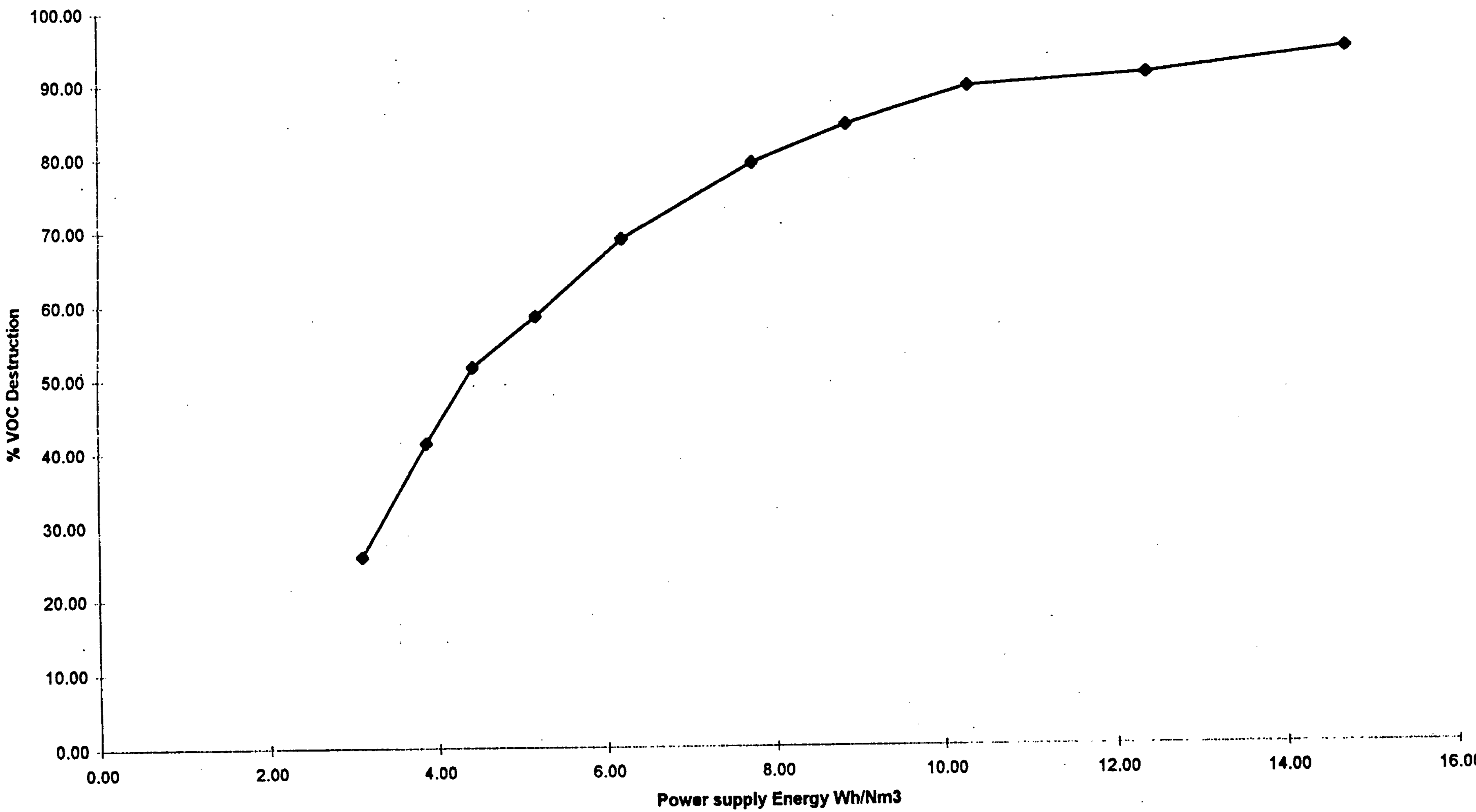
Slide serial no 13

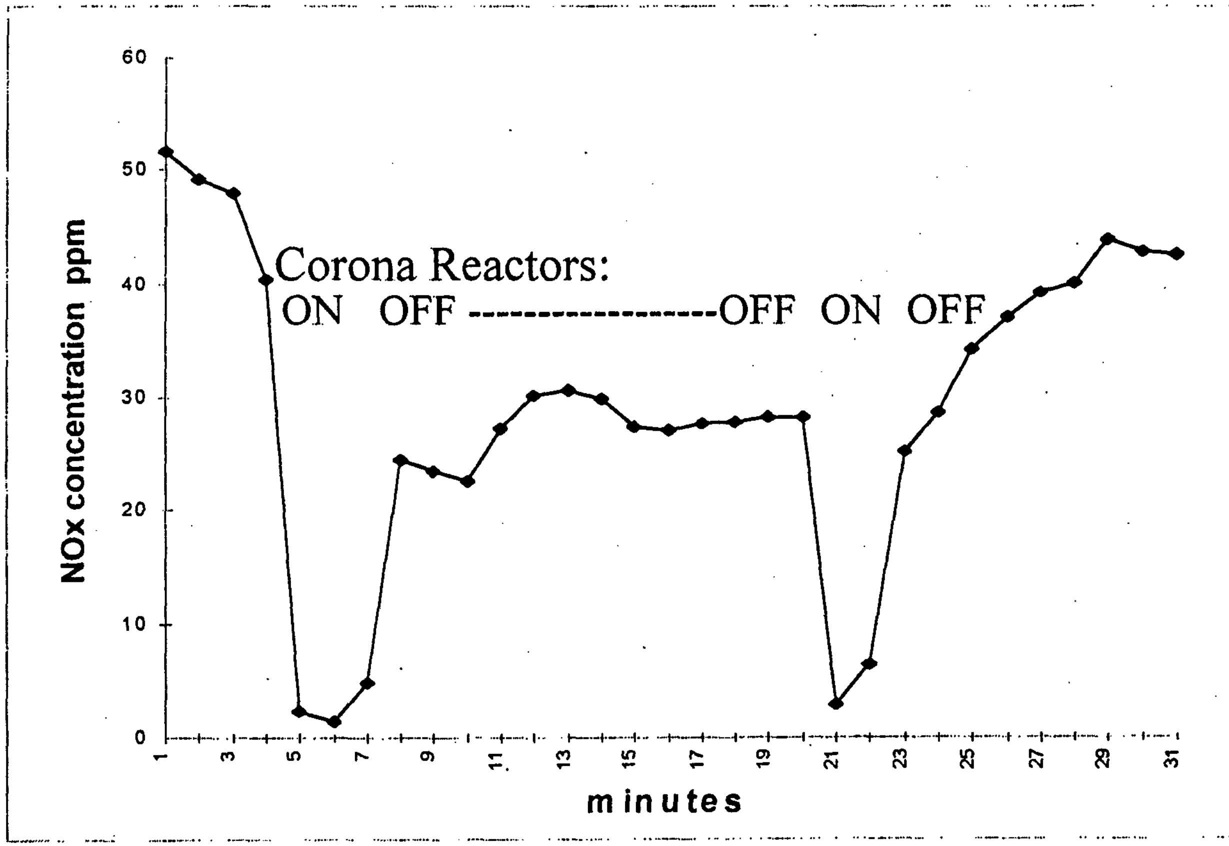
s1K_mdl6 data Chart 184

Culham VOC Toluene Destruction Data



12

NO_x test results at $60m^3/hr$



AEA Technology

Slide serial no 10

Electrically driven

Compact

Low operating costs

Ease of operation

Modular

Easily integrated into existing system

Simultaneous treatment of many pollutants

AEA

AEA Technology

Slide serial no 3

Session 3 - Plasma Treatment Technologies

The Equipment and Technology of Sanitation and Ecological Cleaning of Ships and Water Areas

by Dr. Adam M. Gonopolski
and Dr. Tengiz N. Borisov,
Plasma-Test, Russia

THE EQUIPMENT AND TECHNOLOGY OF SANITATION AND ECOLOGICAL CLEANING OF SHIPS, AND WATER AREAS

Authors: Dr. of Engineering, Prof. Tengiz N. Borisov,
Dr. of Engineering, Prof. Adam M. Gonopolsky

Extremely unfavourable ecological conditions in ports as well as at bases of fleet dislocation are causing the necessity to develop this project. At present time it is necessary to design and develop a sanitation-ecological ship of a new type for collecting and processing of unsorted packed and/or baled waste of ship-, vessel- and other floating facilities- related activities and services, located at ports or outside, as well as for by-products of port activities.

Hereinafter *waste* denotes any kind of waste, containing complete list of chemical and other substances, overflow disposal of which is forbidden by international conventions, as well as land burial is forbidden (pesticides, poisonous chemicals, and other plants' protective chemicals, raw material of a chemical industry, etc.).

This can be applied to road vessels, operating in ports and accepting garbage from approaching ships, (with appropriate seaworthiness), or vessels with increased seaworthiness, capable of moving from one port to another.

Moreover, installation of waste processing equipment aboard large-scale ships is expedient.

But it is necessary to make a proviso, that waste processing equipment can be installed only aboard surface large displacement ships like aircraft carriers, heavy cruisers, battleships. They make longer roads, have from several hundreds up to several thousands of sailors and officers, produce hundreds of kilos of various garbage - from plastic and metal packing of products and other staff. Of course, these ships have enough power supply to spend part of its power resources for waste destruction.

The so called hospital-vessels form a big group of vessels that frequently need to liquidate infectious tools, various medical materials, bed linen and medical tools required for treatment of sick people. This problem becomes extremely acute when hospital-ships work in regions of natural disasters or areas of epidemic, etc.. In all the cases ecological situation in ports, seas and oceans and finally the ecology of all humanity will benefit from this.

It is well known, that annually huge waste quantities are thrown from ships into water that not only causes water and bottom pollution, but frequently becomes the main reason for death of waterfowl, fishes and sea animals.

The philosophy of the project is based on use of the newest technology of plasma-thermal treatment of any kind of waste in a two-chamber tight metallurgical furnace on a slag-and-metal melt surface. The core of the technology is deep thermooxidizing waste destruction during which waste is converted in slag-and-metal melt. Formed waste gas components bubble through liquid layer of slag. After bubbling off-gases go into a waste recovery system and into a gas-cleaning system.

In contradistinction to widely used method of household and industrial waste destruction by its burning with subsequent burying of non-inflammable remnants or more modern process of separation with slow partial oxidising and organic decomposition to have utilised gas (piroliz), plasma processing increases temperature in a zone of partial oxidizing and organic decomposition. In this way it do not only speed up reaction of oxidising and decomposition, but also transfers non-flammable components, divided into oxidising slag and metal phases, into melt. When accumulated, they are periodically released from the unit.

The core technological element of waste destruction process is a plasma furnace, having loading coaxial and linear operating plasmatorches installed on the reaction chamber. The furnace is also equipped by graphite electrodes, used for heating up the bath by direct current transmission through burden. An off-gas waste recovery block with a gas-and-liquid heat-exchanging device, gas cooler and off-gas cleaning. block are consecutively connected to the chamber gas outlet. Air oxygen serves as an oxidiser. Through plasmatorches it is fed into reaction zone, where it is heated up to 2000-4000° C. Gaseous products generated during combustion constantly go through a slag melt layer into a gas-cleaning system, then are thrown out into atmosphere.

Slag melt is drained into an ingot mould; metal melt, when accumulated, goes through an open tape-hole into ingot mould. Besides air heating in plasmatorches, the power supply of the furnace is due to the direct transmission of electrical current through a layer of melt. The furnace operates at various power supplies, that is determined by mode parameters on plasmatorches and their quantity, as well as by current going through the melt and the current generated at the combustion of thermal energy waste.

The case of the furnace is a horizontally placed cylinder, assembled from metal ring sections. The sections are arranged in the following order: a bottom, a combustion chamber, section of cassion cooled partition with an outlet for melt and off-gases at the bottom (bubbling through melt slag) -a bubbling section and a section for melt slag and metal go out (siphon section). An inside of the furnace has two layers of brick. Half-pipes with bottom and top water cooling closed cycle collectors are welded to the outside of the sections, except for a siphon one.

The process is ecologically clean due to high temperatures. There are no resins, phenols, complex hydrocarbons and polluting off-gases in gaseous products.

Melt of slag can be granulated and used in construction, and metal melt as a semifinished item can be sold to metallurgical factories (basis for alloys, products for the follow on refining process). Capacity of equipment incorporated in the technological line determine volumes of processed waste. (number of plasmatorches, capacity of exchange heaters, dust and gas filters, compressors and other equipment).

In accordance with the Decree of Moscow government № 550 dated 05.07.94,a universal bloc-and-module complex for plasma processing of unsorted dangerous medical waste has been assembled and put into testing operation on the territory of the 1-st infection hospital (Moscow, Volokolamskoje Road, N 65). All documentation required for the operation of the complex in a residential area has been co-ordinated according to the set procedure. The present complex has the design similar to that, proposed for installation aboard ships, the capacity being 500 tonnes per year.

Project development has been completed, equipment has been manufactured and tested for the complex with the capacity of 10000 tonnes of processed waste per year for the operation in the Eastern district of Moscow and in the of city Tolyatti, Samara area. All required permissions for construction and operation of the complex has been received from adequate state bodies responsible for protection of the nature and sanitary-and-epidemiological control..

The available documentation on mainframes and modules, configurations of the complex depend on peculiarities of processed wastes, equipment configuration, its components and physical condition of waste, minimisation of pipes and cable-and-hose stud of modules, creation of optimum conditions of equipment operation, rational use of vessel's dimensions, as well as opportunities to use power supply system and engineering networks of a vessel.

The complex, installed aboard the vessel, should ensure ecologically pure, safe technological process and producing untoxical by-products waste treatment and its operation should be in full compliance with requirements on protection of environment and norms of safety precautions. As a result of the project the documentation for manufacturing of an operational model of a ship as well as processing waste technology will be developed.

The next step should be manufacturing of an operational model of a vessel, its operation and start up of serial production of this type

The following tasks can be solved as a result of the completion of the project:

- reduction of technogeneous pressure onto ports zones, including areas of fleet bases location, due to liquidation of dumping grounds, warehouses and waste burial places ;
- reduction of ecological payments made by a port of ship's assignment;
- reduction of costs associated with waste storing and burying::
- payment for waste treatment aboard dedicated ship will add to the budget of any port

Each port will require, at least, one vessel of a designed type.

Taking into account, that the average cost of collecting, packing and processing of unsorted waste in world's large ports is about $ 2000 for a ton, one can calculate the playback time of a specialised vessel, proceeding from the number of treated vessels in ports and their displacement. Thus in 1996, the average number of treated vessels in a Russian port was about 400 units.

In average about 12.0 tons of waste of all types was processed annually.

The playback time of the project (development and implementation) does not exceed two years with the capacity of 5 000 tons per year: the cost of a used vessel is about $ 100-150 thousand, cost of waste treatment equipment - $ 2,5 million and cost of its installation - about $ 0,5 million.

Waste destruction by the proposed method will allow to get rid of dumping grounds in ports, the emanated aroma being far from paradise fragrance, to clean significantly big areas of earth, etc.. The gain is obvious, many-sided.

Let me stop at some technical aspects of equipment installation on military ships and dedicated vessels.

Heavy ships are ideally go with the equipment in question. Let's take, for a example, heavy cruiser-carrier of project 1143.5 According to the data listed in *Rosvooruzheniye* catalogue full displacement of this ship is 55000 т., main dimensions 302,3 x 72,3 x of 9,14 m., time of autonomous raid - 45 days. Power sources capacity is in kW: turbogenerators - 9 x 1500; Diesel-generators - 6 x 1500.

Heavy rocket cruiser of project 1144 accordingly - 24300 т, 251 x 28,5 x 10,33 м, 60 days; turbogenerators 4 x 3000; Diesel- generators - 4 x 1500.

Naturally, the cases of power systems operating at their maximum capacity are very few in number and part of the energy can be directed to the operation of any of the proposed complexes up to the most powerful *PT*-5.

The same can be said about waste treatment installation supplied with compressed air and cooling water, with removal of formed gases, their cooling and cleaning. Each military ship will require an individual approach, but all technical and technological difficulties can be overcome.

I'd like to emphasise the fact, large-scale ships have smooth rocking, and the majority of them are equipped with active, or passive special devices for soothing rocking. As it follows from the above-stated data there are no problems with installation of the equipment aboard similar ships.

The installation of *PT-1 - PT-2*, let's say, aboard a corvette- or guard-, or mine-sweeper- class ship, is not profitable, as none can spend all the generated power to ensure their operation.

There is another case with dedicated ships. Additional number of generators, compressors or other required equipment can be installed aboard the ships to solve the set tasks. Rocking also does not have any significant impact as road waste treatment vessels will be well protected in ports. Other vessels can stop waste procession till the time weather conditions improve.

Due to complex's module configuration it is possible to make necessary arrangements aboard ships fast to install the equipment.

At the scientific-research institute of the Navy, RF designing precomputation was made for a vessel for waste destruction, based on a marine tugboat of 2200 ton displacement, dimensions 77,9 x 13,4 x of 9,0 m. The same was done for an aircraft-carrier (installation *PT*-3) of a *Forrestal type.* These calculations have proved that there is an opportunity to adapt the complex to ships or vessels of any class.

We, *JSC Plasma-Test, Central R&D Institite of the Russion Navy* and organisation *Oceantechnik,* are ready to develop any installation configuration of the modular complexes *PT-1 - PT-5* aboard ships, dedicated for these purposes.

However, Russia nowadays has no funds to finance the creation of waste processing ship.

That's why on behalf of a whole group of developers of this project I propose to start up an international ecological project under which such a waste procession ship is developed and tested at different ports of the world.

* Vice-Admiral of Russian Navy Dr. T.Borisov , is addressing the participants of the meeting with the same proposal in his letter.

Session 3 - Plasma Treatment Technologies

Treatment of Naval Shipboard Waste Using a Plasma Arc Waste Treatment System

by Tim Rivers,
MSE Technology Application Inc., USA

TREATMENT OF NAVAL SHIPBOARD WASTE USING A PLASMA ARC WASTE TREATMENT SYSTEM

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Abstract

As a result of U.S. environmental laws passed during the 1980's, a tremendous amount of effort has been focused on the development of alternative methods or technologies which can be utilized for the treatment of hazardous, radioactive, and demilitarization waste streams as the current methods of disposal either become to costly or prohibited altogether. Plasma technology can provide an attractive alternative for the treatment of these waste streams.

Application of plasma arc technology to the treatment of radioactive, hazardous, and demilitarization waste streams has been shown to effectively provide a final solution for the treatment of these waste streams by destroying all organic constituents and immobilizing all inorganic constituents in a stable waste form. MSE-TA, Inc. has been involved with the evaluation, development, and application of plasma arc technology to the treatment of these waste streams since 1989.

To stay in compliance with upcoming Marpol regulations and maintain their position of environmental excellence within the world naval community, the U.S. Navy commissioned a conceptual design of a Plasma Arc Hazardous Waste Treatment System for installation on board ships. The purpose of the system is for the treatment of shipboard generated waste to preclude the need for dumping waste in the oceans of the world.

MSE-TA, Inc., Pyrogenesis, Inc., and Applied Ordinance Technology, Inc. have developed a unique Plasma Arc Waste Treatment System (PAWDS) to meet the Navy's needs. The system takes advantages of technology gains from the commercial aviation industry and applies these gains to Plasma Arc Waste Treatment.

The Plasma Arc Waste Destruction System has been conceptualized to meet all of the Navy's Requirements for shipboard application.

Plasma Arc Technology Background

Plasma processing is the process in which a plasma torch is used to discharge electrical energy to the torch gases in order to increase the gas temperature beyond that normally attainable by chemical reaction. The plasma torch produces a transferred arc that directly contacts the waste material to temperature sufficient to melt soil (typically on the order of 3,000 °F). The waste is melted by this extreme heat, incorporating any inorganic and metals into a stable matrix. Organic constituents are volatilized by the heat of the plasma and oxidized by air or oxygen.

Many organizations have been investigating plasma technology as a waste treatment alternative for the past few years. MSE, Inc. has been involved with the technology since 1989. While considerable work has been completed, the discussion that follows highlights a few of the key milestones attained by in developing plasma to the point of implementation. The following discussions highlight key accomplishments in the areas of mine waste streams, DOE waste streams, and demilitarization waste streams.

Mine Waste and DOE Waste Streams

Testing and evaluation of Plasma technology for the treatment of various waste streams was started in 1989 with the delivery of the PACT system. After time for installation and start-up activities, testing was initiated in 1991 with a series of joint tests between the Environmental Protection Agency (EPA) and DOE to demonstrate the applicability of the technology to the treatment of the typical mine tailings and DOE buried waste. The culmination of these tests was in 1991 when the EPA considered plasma arc technology as an appropriate technology for remediation of contaminated mine sites.

DoD Ordnance Testing

In 1992 MSE-TA was commissioned by the U.S. Army Research Development and Engineering Center to evaluate plasma technology for use in demilitarization. Different small caliber and hand-held pyrotechnic, smoke, and dye items were selected from the demilitarization stockpile. Testing was limited to small caliber and small hand-held items due to safety concerns associated with testing large items. The items were selected to be representative of the demilitarization stockpile of pyrotechnic, smoke, and dye items in this size range. Live, completely assembled items were used for testing. In addition, two organic spotting dyes downloaded from 6-inch projectiles were selected for testing.

Successful testing of these devices prompted the U.S. Army to select plasma arc technology as the preferred method of destruction for these ordnanaces. A full scale plasma arc ordnance destruction system is under construction by MSE-TA for installation at the U.S. Army's Hawthorne Nevada Ordnance Depot.

Department of Energy (DOE) 100 Hour Testing

In 1993, MSE-TA in a teaming arrangement with Lockheed Environmental Systems and Technology proposed to remediate Pit 9, a mixed radioactive burial pit at the Idaho National Engineering Laboratory. To prove the applicability of the proposed technology, the U.S. DOE required MSE-TA to perform a long duration test using radioactive waste surrogates. The objective for the 100 hour plasma test for the DOE was to prove the reliability and effectiveness of using plasma technology to treat low level radioactive waste streams on a long term production basis. As a result of the successful test, plasma arc technology was chosen to remediate Pit 9 at the INEL.

Shipboard Waste Destruction Using Plasma Arc Technology

As can be seen from the previous discussion, the viability of plasma treatment of waste has been on going for many years and has been proven successful. It is therefore time to start implementing plasma treatment as a solution for some of the problem waste streams facing the navies and commercial cruise lines of the world.

In the late 1960's it became apparent that disposal of untreated solid waste into the waters of the world was not an environmentally acceptable practice. In 1973 and again in 1978 agreement was reached to curtail the discharge of solid waste into the oceans and seas. The International Convention for the Prevention of Pollution from Ships, known as MARPOL 73/78, designated special areas where discharge of solid waste was prohibited. The specific language of MARPOL 73/78 does not strictly apply to warships. Party states (including the U.S.) are required, however, to establish standards for their warships. These standards would require such vessels to conform as closely as practicable with the international standard, without compromising operational effectiveness.

When first written, 33 Code of Federal Regulations §151 specifically excluded warships from the requirements to conform to the provisions of Annex V, *Regulations for the Prevention of Pollution by Garbage from Ships*. The *Act to Prevent Pollution from Ships (APPS)*, as amended by the *Marine*

Plastic Pollution Research and Control Act of 1987, and by the *National Defense Authorization Act for 1994* (DAA) implements MARPOL Annex V for the United States. APPS requires U.S. public vessels including warships to fully comply with MARPOL as implemented in 33CFR. Specific deadlines were imposed:

Plastic discharge prohibition	1 January 1999
Special Area Limitations	1 January 2001
Submarine compliance for both	1 January 2009

When fully implemented, discharges into Special Areas will be restricted to only victual waste (spoiled or unspoiled food) and then only outside of 12 miles from shore.

This inability to discharge solid waste in its original form, requires ships to retain solid waste onboard for extended periods of time. Space, hygiene and morale considerations require that the solid waste be reduced in volume and rendered sanitary and odor free. These new requirements result in a new and more complicated life cycle for shipboard solid waste.

In 1996, a team composed of MSE-TA, Pyrogenesis Inc. and Applied Ordnance Technology (AOT) won a competitive procurement from the Carderock Division of the U.S. Naval Surface Warfare Center to complete a conceptual design of a plasma arc waste destruction system. MSE-TA was selected prime contractor because of its experience in plasma processing. Pyrogenesis was included because of their unique plasma torch and speciality metal design capabilities, and AOT because of their knowledge of military operations.

In performing a design for shipboard applications, several factors were considered important ensure that a successful implementation of the technology could be accomplished. Some of the important design considerations were:

<u>Ship Platform Considerations</u>
- Unit Weight
- Unit Height
- Required Area
- Ship Pitch and Roll
- Energy Requirements
- Shock Tolerance

<u>Personnel Factors</u>
- Operability
- Process Safety
- Unit Cooling
- Crucible Cooling
- Slag Pouring and Handling
- Feed Preparation and Storage

Each of these factors were considered in the design. Trade off studies documented the compromises in the design process. Summaries of these trade studies are discussed below.

Ship Selection Options

The government furnished information identified four different classes of Combat Logistics Force (CLF) ship which could be designated the PAWDS Processing Ship (PPS). The pros and cons of each class of potential PPS is summarized in Table 1. Five criteria were utilized in selecting the proposed processing ship.

Table 1. Ship Selection Options.

Ship Class	Station Ship	Embarked Helo	Electrical Capacity	Space with Flush Deck Access	Materials Handling Equipment
AE	No note 1	Yes	No	Yes note 2	Yes
T-AFS	No	Yes	Yes	Yes note 2	Yes
AO 177 T-AO 187	No note 1	No	Yes	Yes note 3	Yes
AOE	Yes	Yes	Yes	Yes	Yes

Note 1: Designated as shuttle ship when AOE is assigned. When an AE/AO combination replaces the AOE the AO operates as a station ship. Both the AE and AO lack the maneuvering speed to stay with the CVBG during flight operations and high speed transits.

Note 2: Diminishes cargo capacity.

Note 3: Requires construction of cargo deck structure to house PAWDS unit. Available internal space currently being reconfigured for plastic compaction and storage.

Station Ship

Navy doctrine divides CLF ships into two major groups, station ships and shuttle ships. A station ship is one which functions as an integral part of the battle group, capable of self defense in a combat environment, and maneuvering with the battle group. The shuttle ship is intended to travel back and forth between rear supply points and forward areas, bringing resupply to the station ship and possibly the battle group. Only station ships remain with the battle group during operations.

The T-AFS operates differently in the Pacific and Indian Oceans than in the Mediterranean area. In the Pacific each deployed ship is scheduled to receive replenishment from the T-AFS a minimum of once a month and twice a month if feasible. In the Med, T-AFS replenishments are strictly once a month for each ship. Making the T-AFS the processing ship and requiring an UNREP frequency of 6 to 10 times per month would require a radical change in the operating philosophy of the class. There are not enough ships of this class to support both the PAWDS mission and the general stores replenishment mission.

The AE and AO class ships can be assigned as station ships, but this is done only when an AOE is not available. Neither ship is capable of staying with the carrier during flight operations or high speed transits, both 30+ knot evolutions.

The AOE was designed and built as a station ship and is capable of self defense and maneuvering to stay with the battle group.

Embarked Helos

The Navy uses the CH-46 Helo as the logistics airframe supporting Vertical Replenishment (VERTREP). Aircraft carriers and surface combatants do not deploy with logistics helos embarked. Only the Combat Logistics Force (CLF) ships routinely embark the CH-46. The carrier's embarked helo, the SH-3G, is a dual mission aircraft designed for anti-submarine warfare and search and rescue. The surface combatant's embarked helo, the SH-60B, is an antisubmarine helo. Neither the SH-3G nor the SH-60B is currently configured to externally lift triwalls and does not have space to carry one internally.

VERTREP is the preferred method of transfer because it minimizes the generating ships off-station time and will not impact alongside station keeping evolutions.

All of the proposed ships are VERTREP capable in that all have helo platforms installed. The AO is the only class that does not have the helo hangers required for embarking a helo.

Electrical System

From an electrical capacity standpoint the requirement for a single unit in operation is slightly less than 1 MW. There is no surge startup requirement. The AE and the AO-177 classes are restricted in that available electricity supports only a single unit. A second unit requires the addition of a generator with the associated space. The other ship classes have adequate electrical capacity to support two units in operation.

Switchboard distribution systems are limited on all the proposed classes of ships. Onboard ship checks have validated that there is available power and sufficient space for the installation of an additional switchboard.

Auxiliary Systems

Auxiliary systems support is required in the form of salt water, air supply and exhaust, and minimal amounts of chilled and fresh water. Salt water will be used for system cooling and as a source for the reverse osmosis water generating plant. Air supply is needed for the plasma processing and space ventilation. The small dedicated operating station would utilize minimal amounts of chilled water for electronic cooling and space habitability. Fresh water is utilized as the quenching medium in the offgas system. Connection to the ships fresh water system is intended solely as a backup system should the reverse osmosis plant require maintenance. This is a symbiotic relationship in that the reverse osmosis plant could augment the ships fresh water system when not being used for plasma processing. With the exception of the air supply and exhaust systems, co-location of these equipments with the PAWDS unit is not required. These equipments could be placed in any available space within existing pump rooms or machinery spaces.

Space Availability with Flush Deck Access

The AE and T-AFS class ships each have sufficient space only by converting existing cargo space to PAWDS equipment and compacted waste/slag storage. These cargo spaces are currently used to capacity carrying replenishment ammunition and general stores required to support the battle group in both peacetime and in war. Reduction in the cargo capacity of these ships reduces the readiness and sustainability of the entire battle group. A separate study would be required to quantify the impact on either readiness or sustainabilty.

Flush deck access is a significant parameter such that materials handling equipment can have direct access to the space. Without direct access, sailors would have to manhandle each and every individual compacted waste bag.

Materials Handling Equipment (MHE)

All of the proposed processing ships have sufficient materials handling equipment to support the PAWDS operation. Discharge trays from the PAWDS unit are designed to be compatible with MHE and to interlock for storage of the slag billets. The tray will also be utilized in off-loading the slag directly into a truck or dumpster ashore. The weight of the compacted waste bags make it difficult to remove from an upright triwall. Removal of the individual compacted waste units from the triwall will be facilitated by a mechanical platform that rotates the triwall onto its side.

Ship Selection

The AOE-6 class ship was chosen as the primary CVBG processing platform because the ship can perform the PAWDS function with minimal impact on its current mission. The AOE currently operates with the CVBG full time, has materials handling equipment (MHE) and flush deck access storerooms/spaces, has sufficient electrical power generation capacity, and deploys with an embarked VERTREP Helo Detachment. Each of the other class ships proposed lacks one or more of these required capabilities.

Optional Ship Installations

The alternative installations discussed below are considered viable and consistent with real world fleet operations and training evolutions.

Aircraft Carrier

The waste as identified in the solicitation had the aircraft carrier generating approximately 70% of the CVBG solid waste. Compacting, handling, transfer and stowage of this waste is manpower intensive. The only space large enough to store this waste with reasonable accessibility is on the hangar deck, either on the fantail or in the hangar bay itself. With the carrier generating a minimum of 13 triwalls a day, the size of the required space equals the space required for a complete PAWDS installation. Utilizing this space for timely processing of waste rather stowage, eliminates the negative morale impacts of odor and hygiene and would save significant man-hours required just to compact and transfer the waste. The PAWDS unit manpower requirement is less than the manpower required to compact, store and transfer the waste. Onboard waste processing yields significant positive results in sailors morale and performance by keeping spaces odor free, sanitary, and shipshape.

The existence of the PAWDS unit on a carrier reduces the throughput requirement for the CLF based PAWDS unit by an amount sufficient to require a single vice double unit installation. The feasibility and desirability of installing PAWDS on any CLF ship is increased as the space requirement is significantly reduced.

Large Amphibious Ships

Each of the arguments above applies equally to the large amphibious ships. Additionally, evolving Navy Doctrine recognizes the potential to assign the LHD/LHA as the backbone of a battle group. In such situations an AO is normally assigned in support rather than an AOE Marine Amphibious Ready Groups (MARG) although not defined in the solicitation as a battle group, operate in the same littoral as the CVBG, and will require PAWDS support. AOEs are not normally assigned to a MARG. The large amphibious ships carry enough ship's fuel and ammunition that resupply of these commodities is rarely needed. Aviation fuel is required about once per week during operations to support flight operations and refuel any escorting surface combatants. This is normally provided by an AO or T-AO.

Based on the logic above, installation of a PAWDS unit on the large amphibious ships is prudent.

AO/T-AO

With installation of PAWDS units on carriers and large amphibious ships the viability of installing a single PAWDS unit on AO/T-AO class ships should be examined. Waste processing throughput on the CLF ship would be reduced to the extent that a single PAWDS unit would be capable of processing all of the remaining waste. Most training evolutions are conducted by individual ships rather than battle groups. These ships require refueling, and an AO is normally assigned the mission. The installation of a PAWDS unit on the AO's would then support the zero discharge policy when operating close to the coast of the United States.

Hospital Ship

Consideration should be given to installing a PAWDS unit on each of the hospital ships. The units would specifically handle bio-medical waste and other hazardous waste, in addition to the normal waste stream. Recently hospital ships have operated essentially independently in support of humanitarian assistance operations. Thus CLF support would be routinely available. Yet these ships operate in anchorages close to shore, usually inside of the 12 mile zero discharge line.

Waste Storage and Feed Preparation Options

The first option for consideration is storage on the generating ship. The options considered were: Store garbage as produced, Compact waste as produced, or dry the waste, then compact. The factors considered were Area required to install equipment, Area required for stored waste, Cleanliness and complexity of equipment. All factors were given an importance factor between one and five. Table 2 summarizes the feed preparation options.

Table 2. Feed Preparation Options.

	Area Required for Compaction Equipment	Area Required for Stored Waste	Cleanliness	Complexity of Equipment	Totals
Store as Produced	5	1	1	5	12
Compact as Produced	3	5	4	3	15
Dry and Compact	1	5	5	1	12

As the table shows, compacting the waste as it is being produced is the best solution. The concept proposed would install trash compactors in the galley spaces and state rooms where the waste is produced. After compaction, the waste will be stored in half height triwalls until transport to the processing ship.

Waste Feeding Options

After the waste has been transported to the processing ship, the options to be considered are: shred material or feed the waste directly to the PAWDS. For the PAWDS to successfully process the waste, it is felt by the team that shredding the material to approximately 2 inch nominal size is required to fully process the waste without unburned material or excessive particulate carryover. With this thought in mind, feeding the compacted waste was eliminated.

Once the material has been shredded, the options for feeding the waste to the primary chamber are: vibratory feeders, positive displacement feeders i.e. auger type, or Archimedes feeders.
Both Archimedes and vibratory pan feeders were eliminated based on the non-uniform feed rate of the shredded bulk material. It is generally felt by the team that using a positive displacement type feeder in conjunction with a variable speed drive will give the most reliable feed rates.

Processing Chamber Wall Cooling Considerations

The selection of a refractory material for use in a plasma waste destruction system is difficult, since refractory materials are very prone to corrosion and erosion at high temperatures. Conventional furnaces are usually constructed with two layers of refractory: a working refractory capable of resisting chemical and physical attack and an insulating refractory having improved thermal resistance. Such a refractory wall is typically 12 inches thick and extremely dense, about 120 lb/ft^2 of interior surface area. An improvement to the typical refractory wall is to replace the insulating refractory with ceramic fiber insulation, since this type of insulation is lightweight and has better heat resistance. The thickness of the wall is reduced to approximately 7 inches, and the density is reduced to 70 lb/ft^2. However ceramic fiber insulation is extremely vulnerable to corrosion, much more than working and insulating refractories. Furthermore, because of their high heat capacitance, the time required for heating and cooling walls made of refractory is very long and thus it is difficult to perform routine maintenance of components, such as the plasma torch.

An alternative to refractory walls has been developed for the PAWDS, which will result in a wall, approximately 4 inches in thickness and having a weight of 7 lb/ft^2. The hot-face section of the wall is a superalloy sheet coated with a bondcoat and a thermal barrier coating (TBC). The hot face wall is separated from a 3 inch lightweight fiber insulation board by an air gap, through which the cooling air will flow.

Another shipboard PAWDS requirement, not mentioned above, which is to maximize the resistance to shock and vibration, can not be easily addressed by conventional refractory prone to cracking and crumbling; by contrast the wall, proposed here, made of superalloy will have very high shock and vibration survivability.

Plasma Torch Design Options

Plasma torches are grouped into two classifications, transferred arc and non-transferred arc. East torch classification has its unique advantages. In the transferred arc mode, the molten bath acts as the cathode and efficient joule heating of the slag is performed, on the order of 90%. However, during start up, the solidified slag is not electrically conductive, thus nontransferred operation is required. A nontransferred arc torch may operate independent of slag conductivity because both the anode and cathode are housed within the torch. Past designs have incorporated two separate torches, one of each type to accommodate the changing furnace conditions.

A dual mode angled torch was designed for the Navy PAWDS. The primary melting torch is a side-mounted, angled, dual-mode torch, capable of operating in nontransferred and transferred mode. The primary torch has been designed to be a side-mounted, angled torch for two reasons:

(I) Side mounting reduces the height requirement associated with a top-mounted torch.

(ii) Maintenance of the torch is simplified by having a torch which can easily be removed from the side and one which the active part of the torch can easily be removed and replaced quickly with a spare.

The primary melting torch also offers a unique feature which permits conversion between transferred and nontransferred mode.

Crucible Cooling Considerations

There are two kinds of operating crucibles which were considered for the PAWDS chamber: the hot wall crucible made of a heat insulating refractory material and the cold wall crucible made of a heat conducting material, usually metal and usually water cooled. Refractory crucibles are widely used in industry, for example in the steel making industry. The advantage of refractory crucibles is that the energy losses through the crucible are minimal, thus minimizing the energy requirements of the torch. However, refractory crucibles are not reliable because of the rapid chemical erosion of the refractory due to the aggressive chemicals in the slag. Furthermore, the weight of the crucible is very high due to the thick layer of refractory (150 lb/ft^2 of surface area) that must be used.

Cold wall crucibles require the use of a cooling fluid, which is usually water. Because the crucible operates at a relatively much lower temperature, than the temperature of the molten slag, the slag solidifies at the surface of the crucible protecting the crucible from the aggressive chemicals contained in the molten slag. Water-cooled crucibles have been used in the past and are still being proposed for some applications, however, there is a great hazard associated with water-cooling. A small puncture of the surface of the crucible will result in a rapid vaporization of high pressure water therefore causing an explosion under the slag melt.

An alternative safe method for cooling a cold wall crucible is proposed for the PAWDS using the air required for combustion of the waste to cool the crucible wall. In order to increase the heat transfer between the crucible and the flowing air, the air cooling passage is filled with a metallic porus packing through which the air passes. This design eliminates refractory contact with the slag and eliminates the safety hazards associated with water cooled crucibles.

Slag Pouring Options

A number of different designs were considered for pouring the slag into a mold. The major design requirements which have been addressed include:

- Guarantee of complete processing of the waste in the crucible
- Maintenance of the slag tap hole or lip
- Operation with different types of waste
- Control of slag pouring
- Ability to operate under ship's pitch and roll conditions

The slag pouring options considered include two types of overflow crucibles, a tiltable crucible and an induction plug. In both overflow tap designs, the slag is allowed to drain continuously as the level in the crucible rises. Both designs can operate with different types of waste. Despite the simplicity of these slag pouring options, the control of the pouring operation is impossible. Furthermore, cleaning of the tap hole is required and must be accomplished by the primary torch or by an auxiliary torch . One important disadvantage with the first overflow tap design, is that there is no guarantee of complete processing of waste, since freshly fed waste may be entrained with melt.

The tiltable crucible approach, involves the rotation of the crucible about its horizontal axis for the pouring of the slag. Advantages associated with this type of crucible design include the guarantee of complete processing of waste and the control of the slag pouring operation. The lip may be cleaned with the primary torch and this type of design may be used with a variety of waste. The main disadvantages for the tiltable crucible are its complexity, since it must be hydraulically lifted several times a day during operation and more importantly, the difficulty in its use on board ships due to the difficulty in pouring during pitch and roll conditions.

The final option considered is a crucible having an induction plug on the bottom. The most important advantage of this design is its ability to control of the slag pouring process using induction heating. The induction plug guarantees the complete processing of waste, may be used for different waste streams and is not affected by the pitch and roll conditions at sea. Based on the advantages of the induction plug, this option was the preferred choice and was selected for used in the PAWDS conceptual design.

Handling and Storage of Slag

Past designs of plasma arc treatment systems included casting the slag into 55 gallon drums or in large molds. These options were discounted for the PAWDS because of the complexity of handling ingots as large as 1,000 pounds.

Small 50 pound ingots were chosen in order to allow easy handling by a person on board the ship instead of the heavy mechanical equipment which would be required to move larger ingots. The ingots, after cooling for 10 hours in the slag cooling chamber, are automatically loaded on a pallet which can hold five ingots. This design simplifies the handling requirements since pallet jacks already aboard ship may be used.

PAWDS DESIGN

Processing Ship Volume Generation Design Basis

The PAWDS unit conceptualized is sized to process a typical battle group waste stream at a throughput of 525 lb/hr. The battle group waste composition and design basis feed stream is shown in Table 3. The composition of the waste is shown in Table 4.

Table 3. Daily Solid Waste Generation for Battle Group.

#/Class of Ships	Crew per Class	Generation lb/day
1 CVN	6,286	11,126
2 CG	818	1,448
1 DDG	303	536
1 CGN	629	1,113
2 FFG	440	779
1 AOE	630	1,115
TOTAL	9,106	16,117

Table 4. Design Basis Feed Stream.

Waste Category	Percent of Total	Waste Input lb/hr
Paper/Cardboard	62.7	329.2
Food	6.8	35.7
Steel	15.3	80.3
Aluminum	7.9	41.5
Glass	7.3	38.3
TOTAL	100	525

To maintain the waste processing requirements, it is conceptualized that two individual PAWDS units will be installed on the AOE 6 class ship. Two units were selected to maintain redundancy in the units and maintain partial processing capacity should the ship or a PAWDS unit not be available for processing

Current operating rules for deployed ships require a minimum of 85% ship's fuel onboard. At nominal peacetime steaming rates this normally requires refueling every third day. Accordingly, based on government provided waste generation rates, surface combatants will generate about 3 to 6 triwalls (48 ft^3 per triwall) of compacted garbage between off loads to the host processing ship. Table 5 shows the estimated generation rates, storage requirements and number of transfer loads required to support three day and five holding cycles.

Table 5. Waste Generation and Transfer Requirement.

SHIP CLASS	GENERATED VOLUME FT^3/DAY	COMPACTED VOLUME FT^3/DAY	3 DAY TRIWALL GENERATION	5 DAY TRIWALL GENERATION
CVN (note 1)	1496	500	39	65
2 CG	195	65	6	10
DDG	72	24	3	5
CGN	150	50	6	10
2 FFG	105	35	3	5
AOE (note 1)	150	50	6	10
TOTAL	2,168	724	63	105

Note 1: It is unnecessary for ships which have PAWDS units installed to compact the trash prior to introduction into the PAWDS unit. These results are consistent with the 1996 study of shipboard solid waste generation sponsored by the Office of the Chief of Naval Operations, Code N45.

Surface combatants will have to allocate sufficient storage space below decks for this compacted waste. Weather deck stowage is preferable from a space standpoint, but impracticable from a heavy weather perspective. Accessibility, handling, and container integrity are all questionable under adverse weather conditions.

Support of carriers and amphibious ships poses increased handling and storage issues. Seventy percent of the identified waste stream is generated by the aircraft carrier and an analogous situation would exist for large amphibious ships.

Maximum triwall weight is expected to be less than 1000 lbs. This is less than 50% of the nominal operating capacity of the VERTREP helicopters and the associated materials handling equipment leaving a wide margin for loading due to variation in composition of the waste stream being generated.

Waste Processing System

Figures 1 and 2 show two general arrangement concepts for PAWDS installations aboard ship. Figure 1 depicts a single PAWD installation when co-location is not possible or desired. Figure 2 illustrates a co-located PAWDS system. The following sections describe the installation of a single PAWDS unit. Weight and area savings are expected by using a co-located system.

Figure 1. Single PAWDS Installation General Arrangement

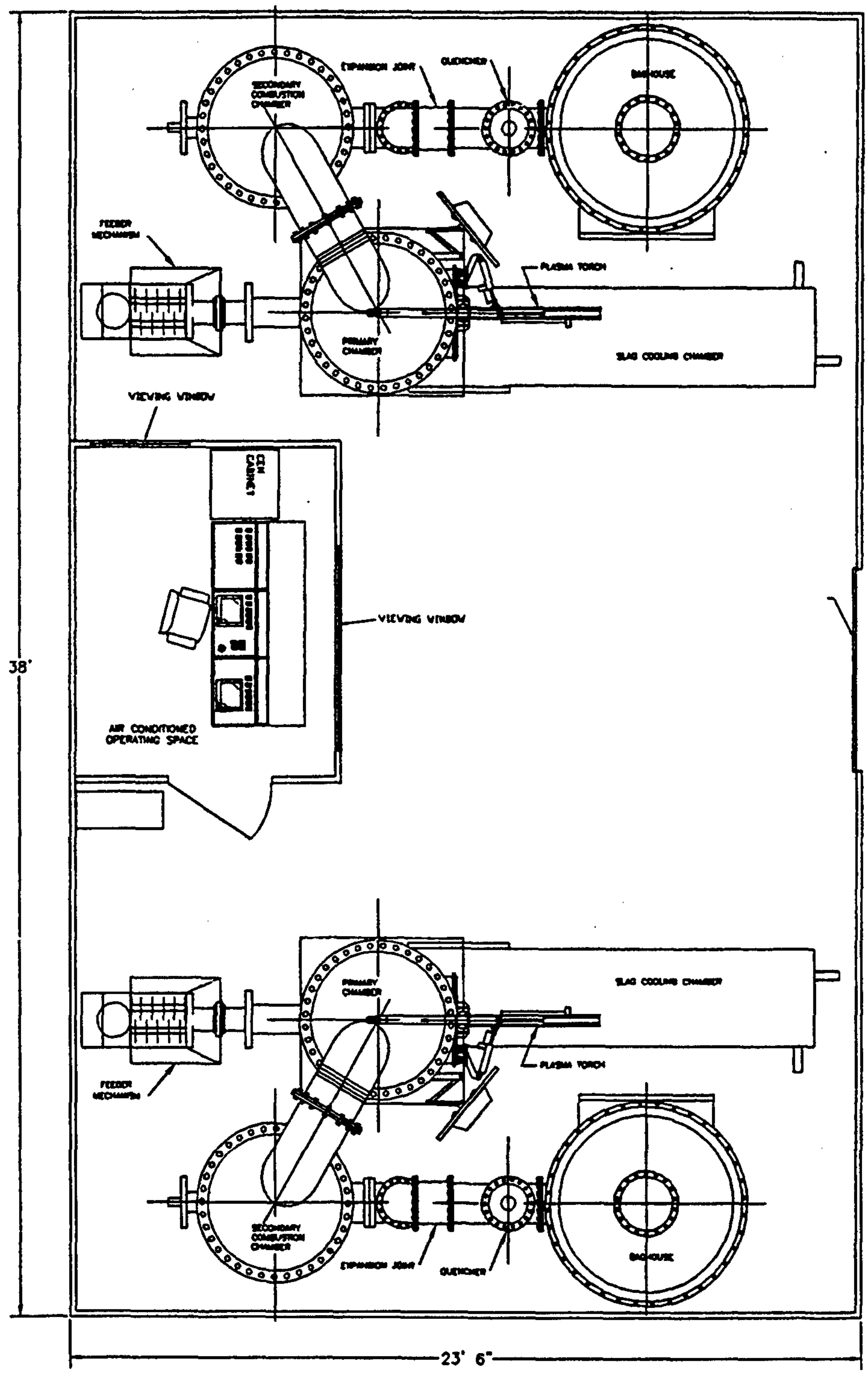
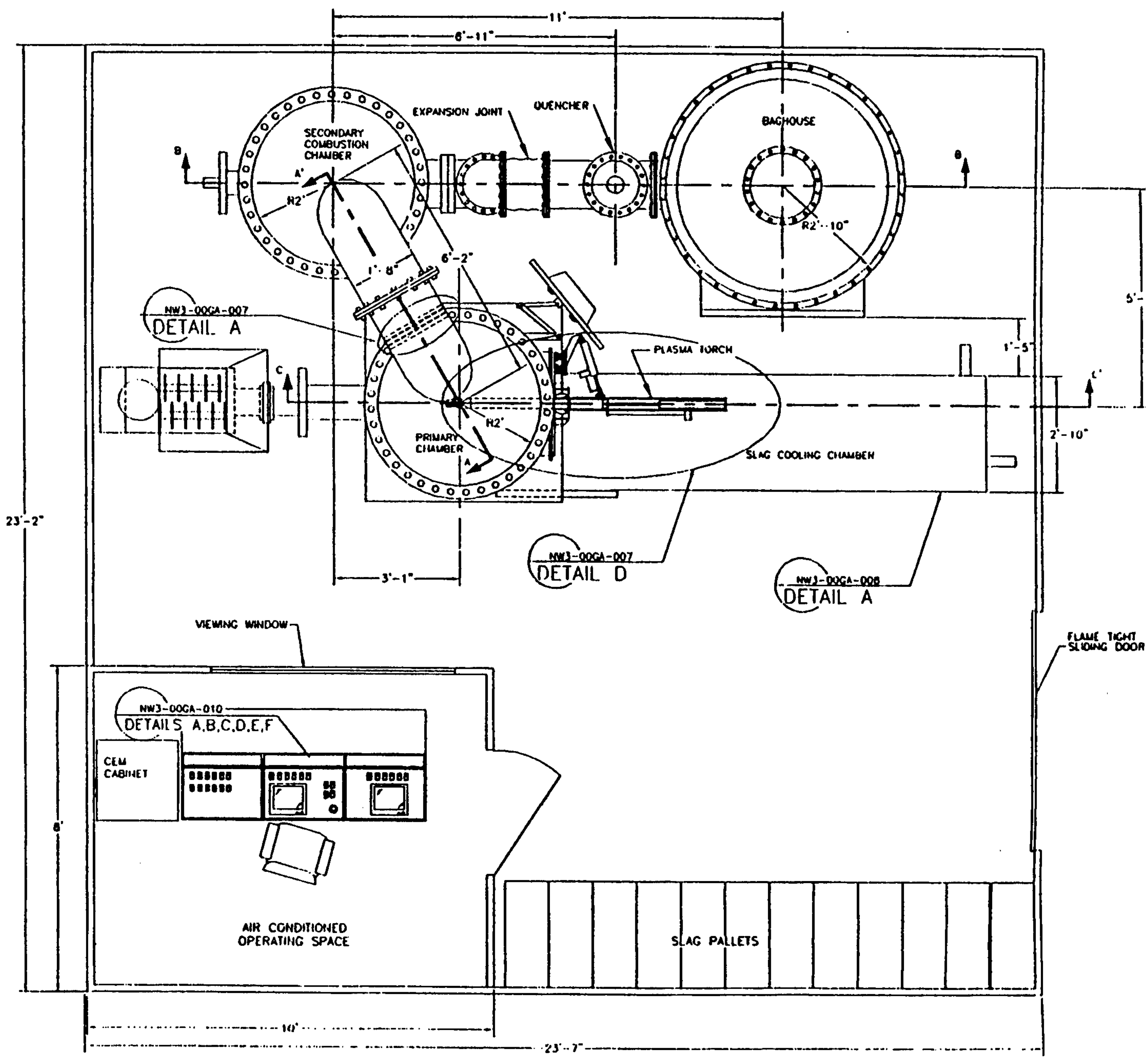


Figure 2. Dual PAWDS Installation General Arrangement.



Processing Chamber Feeder

The material processing chamber selected for the PAWDS unit is a two stage shredding feeding system. As the waste is received from the generating ship, it is stored in half height triwalls until ready for processing. It is envisioned that the compacted waste will be loaded one at a time into the shredder chamber. The door of the shredder will be interlocked with the feed isolation valve below to eliminate any chance of air being drawn through the system while loading the waste. Once the waste is pushed through the isolation door, the waste rolls down a gravity roller conveyor into the shredder unit.

Once the waste has been shredded, the waste falls by gravity into the feed auger section of the system. The feed auger section consists of a helical screw inside a hardened wear resistant tube. The screw is variable speed to precisely and accurately feed the waste to the PAWDS. An isolation valve is mounted at the end of the tube which will separate the feed system from the processing chamber.

Primary Chamber

Thermal destruction of waste occurs in the primary chamber, resulting in the gasification and combustion of organic material and the melting of inorganic material which forms slag. The primary chamber consists of a large light weight refractory lined, gas combustion chamber, a crucible, which contains the molten slag during operation and a melting plasma torch. The chamber is 4 feet in height and 4.5 feet in diameter, providing a residence time of 1 second in the primary chamber. The inorganic melt is maintained at approximately 2,800 °F in the crucible by the operation of the primary torch, while the organic component of the waste is gasified and combusted at 2,000 °F. The waste will be fed into the primary chamber via an auger continuously rather than batchwise. The waste stream will be fed at approximately the same rate as it is gasified. Continuous feeding provides a fairly uniform gasification rate and temperature distribution in the gas mixing zone.

All of the combustion air, with the exception of the air used for the SCC torch, will be introduced into the primary chamber for two reasons: (i) the slag will be highly oxidized and therefore more leach resistant and (ii) combustion will occur in the primary chamber, thus minimizing the energy requirement of the torch during operation since the energy from combustion will aid in maintaining the gas at 2,000 °F.

One disadvantage associated with the introduction of all of the air in the primary chamber is that turbulence is created, resulting in the entrainment of large, light weight solids in the offgas. In anticipation of this potential problem a high temperature arrester has been included in the design of the Navy PAWDS, which will be located between the primary and secondary chambers. The arrester is essentially a tube filled with a series of staggered rods, that will prevent larger particulate from leaving the primary chamber entrained in the offgas stream. The material selected for the arrester is silicon carbide. Silicon carbide has excellent thermal shock resistance and also exhibits excellent corrosion resistance up to temperatures of 2,200 °F.

Secondary Combustion Chamber

The offgas from the plasma arc furnace, will be processed in the secondary combustion chamber (SCC). The SCC will be maintained at temperatures between 1,800 °F to 2,200 °F, by a 100 kW non-transferred arc plasma torch. The secondary combustion chamber, is 7 feet in height and 4.5 feet in diameter, resulting in an additional 1.5 seconds of residence time.

The SCC has been designed to have two compartments. In the top section, turbulence and good mixing are promoted via the injection of the plasma from the plasma torch. A disc, having an opening of approximately 12 inches separates the two compartments of the SCC. Once the offgas passes through the disc opening, laminar flow is promoted. This slowing down of the offgas stream allows time for any residual organic material and/or products of incomplete combustion to react with the oxygen. The laminar flow region also will allow larger particulate to drop out of the offgas stream before the stream exits. As in the arrester, silicon carbide will be used for the disc because of its resistance to thermal shock and corrosion.

Light Weight Thermal Barrier Coating Wall

The refractory wall of the primary and secondary chambers must maximize reliability through long life and provide good thermal performance, while minimizing size and weight impacts. All conventional refractory materials, including alumina and brick type refractories, are unable to meet all of the requirements requested by the Navy for shipboard use. For instance, in order to ensure good thermal performance, a thick layer of working refractory must be used at the expense of size and weight. Furthermore, refractories are not very reliable due their short life when operating at high temperatures in hostile chemical environments.

The wall design proposed for the Navy PAWDS primary and secondary chambers is based on technology developed for turbine engines, where strength at high temperatures, energy efficiency, and light weight are paramount. Pyrogenesis''s extensive experience in the application of thermal barrier and oxidation resistant coatings on hot section components in gas turbines, have been essential in the design of the customized refractory furnace wall. Thermal barrier coatings (TBC's), coupled with air-cooling, result in a significant reduction in weight when compared to refractory lined furnaces, and also result in an increase in energy efficiency since the preheated air will be used for oxidation in the furnace.

Torches and Power Supplies

The PAWDS will be equipped with two plasma systems, one which will be used for the heat source in the primary chamber and the other in the secondary combustion chamber. Air will be used as the plasma-forming gas. Using air will eliminate the need for gas storage cylinders such as those used when argon or nitrogen is used.

The primary torch is a side-mounted, angled, dual-mode torch, capable of operating in non-transferred and transferred mode. The primary torch has been designed to be a side-mounted, angled torch for two reasons:

(I) Side mounting reduces the height requirement associated with a top-mounted torch.
(ii) Maintenance of the torch is simplified by having a torch which can easily be removed from the side and one which the active part of the torch can easily be removed and replaced quickly with a spare.

The primary torch also offers a unique feature which permits conversion between transferred and non-transferred mode. Operation of the torch in non-transferred mode, using the molten bath as the anode is very desirable since this mode of operation has a very high torch efficiency, typically about 90%. However, during start up, the solidified slag is not electrically conductive, thus non-transferred operation is required. The melting torch permits conversion from non-transferred to transferred mode by connecting the torch nozzle and the melt to the power supply in parallel and opening the contact to the torch to transfer the arc.

The plasma system for the primary chamber has been sized for a maximum operation at 360 kW electrical. The primary torch will maintain the molten pool at approximately 2,800 °F and will provide oxygen for the oxidation of the inorganic material. Mixing of the molten bath will occur as a result of the impingement of the plasma jet on the surface of the molten pool, rotation of the arc attachment and cathode phenomena occurring in the molten bath during the transferred mode. The torch movement is controlled by three hydraulic actuators so as to have 3-axes of movement. The vertical position of the torch is maintained automatically to maintain a set voltage as it is translated over the crucible in order to achieve uniform melting.

The PLC is programmed to move the torch about the molten pool which promotes even slag heating and thorough mixing. This automatic mixing program may be over-ridden by the operator if necessary, but allows the untrained operator to learn the system.

The secondary combustion torch, operating at a maximum of 100 kW electrical, will be used as needed to maintain a temperature in the SCC of 2,000 °F.

The power supplies for the torches will be multi-pulse SCR controlled rectifiers with variable output voltage up to 400 V for both the primary torch and secondary torch. The power supplies will be of a MK-86 design built by Magnetek, which meets MIL-STD-461 requirement for electromagnetic emissions interference (EMI). The power supplies will have water-cooled instead of air cooled components chokes and transformers to reduce size and weight.

Stationary Crucible

Due to the impractical use of refractory crucibles and the hazards associated with water-cooled crucibles, an air-cooled crucible design was developed for use in the Navy PAWDS. The crucible is a half-ellipsoid, having a circular cross-section. The shell of the crucible will be made of either copper backed stainless steel or nickel. Air flows through a metallic packing housed in a passage within the crucible. The metallic porus packing material is used to promote heat transfer from the crucible wall to the air.

Slag Pouring

The crucible, as described earlier, is equipped with an induction melting coil on the molten slag tap hole. The most important advantage of this design is its ability to control the slag pouring process using induction heating. The induction melting coil guarantees the complete processing of waste, may be used for different waste streams and is not affected by the pitch and roll conditions at sea. Preliminary sizing of the induction coil and power supply indicates The induction power supply is preliminary sized for 50 kW, 200 Hz. With this high frequency power supply, it is felt that a high temperature, flux resistant metal such as zirconium or tantalum will be used for the induction coil lining.

Slag Chamber

The slag cooling chamber is essentially a water-cooled rectangular chamber where the slag ingots are allowed to cool for approximately 10 hours. The molten slag is poured, via the induction plug, into a mold, located below the plug. Slag will be poured from the crucible into a mold every 12 minutes. The weight of each ingot is controlled by a compensated load cell, so as to ensure that each ingot will not exceed 50 pounds in weight. The slag will be allowed to cool in the mold for about 10 minutes before the two halves of the mold are pulled apart by hydraulic pistons. To ensure that the slag ingot does not shift during the opening of the mold, guides on the bottom plate have been incorporated in the design. Once the ingot is freed from the mold, it is pushed by the primary transport cylinder into the cooling chamber. The chamber has a water-cooled bottom which will decrease the time required for cooling. The ingots will travel through the chamber, pushed by the lateral transfer cylinder and the secondary transport cylinder. The ingots will finally end up on a pallet, which holds five ingots. One pallet must therefore be removed every hour. Water cooled removable panels are installed on the side of the slag cooling chamber to provide access for maintenance of the slag chamber. Slag discharge will be into reusable metal pallets configured such that they are stackable. Using MHE, the cooled slag trays can be moved a storeroom for storage until transfer is possible. Proposed storage aides would be of the existing pogo stick variety currently in use. Slag pallets would be stacked in rows accessible to the MHE. Below deck stowage is desirable to keep from raising the ships center of gravity.

Off-loading from the processing ship inport will be by a combination of MHE and long reach pier side cranes. Trucks would then move the slag to an appropriate shore side location.

Offgas System

The combustion offgas will exit the secondary combustion chamber at a temperature of 2,000 °F. The combustion offgas will contain particulate and trace amounts of SO_2 and NO_X. For the Baseline Design, the temperature of the offgas stream will be reduced by quenching with fresh water, and the particulate will be removed by passing the offgas stream through a baghouse filtration device. The offgas will be moved through the primary chamber, secondary chamber, and offgas equipment by an induced draft blower. Emissions will be monitored by a continuous emissions monitor which will take samples from downstream of the blower.

The first part of the offgas system is a quench with water to reduce the temperature of the combustion offgas from 2,000 °F to 500 °F. The offgas stream cooling will be accomplished by direct-contact gas-liquid heat transfer that is designed to take advantage of the heat transfer that occurs when water is vaporized. The outlet temperature of 500 °F for the proposed quench design was selected to ensure the water from the combustion process, and the water used for quenching, will stay in the vapor phase until the offgas stream is vented to the atmosphere. The water used for quenching is proposed to be fresh water. Seawater can not be used because the evaporation of the water as it comes in contact with the hot offgas stream will leave solid salts.

The quenched offgas stream will leave the quench vessel and enter the baghouse for removal of particulate. The baghouse filter is used to mechanically scrub particulate carry-over from the offgas stream. Baghouse filters are sized by dividing the actual cubic feet per minute of offgas by a cloth ratio factor. The industry standard for cloth filtration is normally four cubic feet of gas per minute per square foot of bag fabric.

Because of height limitations, the bag filter design for the PAWDS offgas stream is a round vessel approximately 6 feet in diameter. The fabric material proposed for the PAWDS is a high temperature Nomex™ or fiberglass fabric. This fabric is designed to withstand the proposed 400 °F temperatures of the offgas stream. The vessel is constructed of aluminum to minimize weight and is epoxy coated on the inside to prevent chemical attack from the offgas. The bags are automatically cleaned by back pulsing the bags with a blast of compressed air. This air blast effectively cleans the bags and reduces the pressure drop across the filters. A clean-out port is installed in the bottom of the vessel for attachment of a vacuum. It is expected that the PAWDS bag house will require cleaning approximately every 250 hours of operation. After particulate scrubbing, the offgas exits the offgas system through the induced draft blower.

The function of the induced draft blower is to maintain the entire PAWDS system at a negative pressure. With negative pressure in the system, any possibility of fugitive gas emissions is eliminated. A redundant spare blower was selected for the system to maintain the system at negative pressure should one blower fail. Prior to exiting the stack, the emissions are sampled using a continuous emissions monitor (CEMS).

The CEMS selected for the PAWDS is a mass spectrometer based system for assurance that the air quality form the units are acceptable. The advantages of using a mass spec based system are that it can be set up for complete and automatic calibration as required, it has high speed analysis capability of up to eight gas components simultaneously in a range of 2 to 250 Atomic Mass Unit (AMU).

Auxiliary Systems

Combustion Air Blower

The combustion air blower supplies the air necessary for cooling the light weight chamber walls. This heated air is then introduced into the primary chamber for combustion of the organic waste. Upstream of the combustion air blower, the sea air is filtered using Navy standard HEPA filters for sand and salt removal.

Fresh Water Source

In an effort to minimize impacts on ships supplies, a reverse osmosis (RO) unit is needed to supply fresh water for the PAWDS. Reverse osmosis desalinates seawater by forcing the seawater through semi-permeable membranes at high pressure to effectively filter out the majority of dissolved salts, organic matter, and suspended solids. When filtering seawater, approximately 30% of the incoming water is recovered as fresh water; the remaining water is discharged as brine. The present concept for the seawater supply is the return line from the DI water cooling heat exchanger. This concept of using heated water increases the efficiency of the process.

Another source of water that should be explored with further testing is the use of grey water from the ships showers as a feed stock for the unit. Purifying grey water substantially increases the efficiency of the system approaching 80%. This concept could possibly eliminate 26 tons/day of grey water from the ship.

Sea Water Source

The PAWDS conceptual design assumed the ships fire water system as the source for seawater cooling. Seawater cooling will be routed to a central heat exchanger where the heat will be removed from the PAWDS unit.

Deionized Cooling Water Unit

The deionized cooling water unit is designed to remove the heat picked up in the water cooled passages of the entire PAWDS unit. The components of the D.I. unit are: head tank, pump, D.I. column, and heat exchanger. The entire unit will be mounted on an aluminum skid with an approximate floor area of 32 ft^2 and weight of 200 lb.

The head tank of the PAWDS is conceptually sized to be a two foot diameter tank, six feet high for worst case sizing requirements, it is assumed to be epoxy lined carbon steel construction. In normal operation, the water level in the tank is designed to be five feet, which equates to 117 gallons of water. This size tank is required as a minimum to maintain water in the system in the event of a catastrophic water leak. The head tank is initially filled and maintained at a constant level by receiving water from the RO unit for the fresh water quench. The DI column is used to increase the quality of the fresh water from the RO unit. To maintain water quality, a slipstream, normally less than 1 gallon is recirculated through the bed any time the cooling water pump is in operation. The heat exchanger to be used for cooling the PAWDS is a plate and frame heat exchanger. The plates are manufactured of titanium to save weight and prevent salt water corrosion.

Data Monitoring

A Personal Computer based data monitoring system is proposed for collecting data during the operation of the PAWDS. It is conceptualized that the PLC control system will supply input\output points through a data highway system. This system architecture allows the flexibility to monitor and record as many points as felt necessary.

Power Requirements

Electrical distribution for the PAWDS has been conceptualized to come from the ships main motor control center. Worst case total connected load to the ships electrical system is estimated at 1.763 MW at full load.

Ship Integration

Required Operators

Operation of the PAWDS system (2 units) is anticipated to use one fully trained operator to perform maintenance and oversee the operation of the two units. Assisting the trained operator would be two untrained operators unloading waste on the feed loading deck. It is anticipated that these two operators would be able to simultaneously load the two units if they are co-located. Operation of the PAWDS unit would also require one control console operator for system operation. With these personnel numbers as stated, the total crew per shift for the PAWDS operation is five.

Component Weights

An estimate of the PAWDS weight was completed using available vendor data and engineering estimates. Table 6 summarizes the estimated weight of one complete PAWDS unit when installed shipboard. If two units are installed shipboard, some weight saving may be attained by co-locating the units and sharing components.

Table 6. Navy PAWDS Component Weight Summary (1 Unit).

	Dry Weight (lb)	Wet Weight (lb)
Primary Chamber	11,210	15,980
Slag System	2,450	2,700
SCC	4,815	4,990
Feeder	1,750	1,750
Offgas System	5,005	5,005
Controls	1,600	1,600
Auxiliary Systems	6,975	8,655
Total Weight	33,805	40,680

6.0 Recommendations and Conclusions

Upon initiation of the design, the task at hand was to push the technology envelope for plasma waste destruction systems. Plasma waste treatment systems in the past have been heavy, bulky and had little consideration given to compactness and ease of operability. The new design incorporates many new and innovative features, yet reflects years of operational experience to ensure an operable and reliable system. The design team feels the proposed design is unique and will meet the Navy requirements for a state-of-the-art shipboard plasma arc waste destruction system.

The proposed system takes advantage of years of operational experience, capitalizes on standard industrial technologies, and the use of specialty materials from the commercial aviation industry. This combination of experience, unique use of standard technology from other industry's will help to meet the stringent requirements necessary for deployment of a shipboard plasma arc waste destruction system. In the development of this unique system, both theoretical analysis and testing were utilized to assure the Navy of the reality of the proposed design.

Because of the innovative features of the system, the next logical step is the pilot scale testing of the system. When viewed as a total treatment train, a plasma arc system is essentially a combination of many standard, proven components. While there is validity to testing the total treatment system, in the current environment of reduced budgets, it is prudent to focus on those new and unique features of the system.

As a means to verify system performance and keep cost to a minimum, we recommend the fabrication and testing of the primary processing chamber. Most of the unique and innovative features associated with this proposed system reside in this subsystem.

Optimization of the primary chamber can be accomplished with minimal expense by building and testing it at a facility that currently has many of the required utilities and subsystems. This testing will provide the pilot scale test data necessary to prove the validity of the concept.

In summary the system presented in the report reflects many new and innovative features such as:

- Lightweight super alloy wall,
- Angled torch,
- Air cooled crucible,
- Retractable mold slag chamber,
- Silicon carbide spark arrestor, and
- Plasma fired secondary combustion chamber.

We feel the system proposed, meets the original challenge to push the technology envelope yet provide a real world solution to the Navy's shipboard waste problem.

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TREATMENT OF NAVAL SHIPBOARD WASTE USING A PLASMA ARC WASTE TREATMENT SYSTEM

Timothy J. Rivers
MSE-Technology Applications Inc. (MSE)
P.O. Box 4078
Butte, MT 59702

October 30, 1997

BACKGROUND

- Started working with plasma arc technology for the treatment of wastes in 1989

- Past Demonstrations of the technology included:

  - MineWaste
    Resulted in the U.S. Environmental Protection Agency (EPA) to designate plasma arc technology as a solution for mixed hazardous organic and heavy metal waste.

  - Surrogate Radioactive Waste
    Results of testing led the U.S. Depart of Energy (DOE) to select plasma arc technology as a treatment technology for remediating Pit 9 at the Idaho National Engineering and Environmental Laboratory.

BACKGROUND Cont'd

- Ordnance Waste

  Successful test results led the U.S. Army to select MSE to design and build a plasma arc treatment system for ordnance disposal at the Hawthorne Nevada ordnance depot.

Technology Migration

- Development of transportable treatment systems to allow for on-site treatment.
- Development of just in time processing for boiler ash using plasma arc technology.
- Development of light weight, compact systems for treatment of shipboard waste for both commercial and military applications.

DESIGN TEAM BACKGROUND

- A design team consisting of MSE, PyroGenesis, and Applied Ordnance Technology was assembled to perform a conceptual design to address if plasma arc technology is applicable to Navy shipboard waste. The design team possessed these unique qualities:

  - MSE-Technology Applications
    Plasma Operations
    System Design
    System Start-up

  - PyroGenesis
    Plasma Torch Expertise
    Speciality Material Applications
    Research and Development

  - Applied Ordnance Technology
    Shipboard Integration
    Shipboard System Knowledge

MSE

SHIPBOARD WASTE TREATMENT SYSTEM DESIGN TARGETS

- Develop a creative system approach which will meet the following design goals:

  - Light weight
  - Compact Size
  - Reliable
  - Operable by moderately trained staff
  - Serviceable
  - Safe
  - Use existing equipment as much as possible
  - Environmentally compliant

CLASSIFICATION OF WASTE

Waste Category	Generation lb/man per day	Percent of Total
Paper/Cardboard	1.11	62.7
Food	0.12	6.8
Steel	0.27	15.3
Aluminum	0.14	7.9
Glass	0.13	7.3
TOTAL	1.77	

DESIGN BASIS

Processing Ship Volume Generation Design Basis

Waste *Generation and Transfer Requirement*

SHIP CLASS	GENERATED VOLUME FT^3/DAY	COMPACTED VOLUME FT^3/DAY	3 DAY TRIWALL GENERATION	5 DAY TRIWALL GENERATION
CVN (note 1)	1496	500	39	65
2 CG	195	65	6	10
DDG	72	24	3	5
CGN	150	50	6	10
2 FFG	105	35	3	5
AOE (note 1)	150	50	6	10
TOTAL	2,168	724	63	105

Note *1: It is unnecessary for ships which have PAWDS units installed to compact the trash prior to introduction into the PAWDS unit. These results are consistent with the 1996 study of shipboard solid waste generation sponsored by the Office of the Chief of Naval Operations, Code N45.*

THROUGHPUT REQUIREMENTS

Daily Solid Waste Generation for Battle Group

#/Class of Ships	Crew per Class	Generation lb/day
1 CVN	6,286	11,126
2 CG	818	1,448
1 DDG	303	536
1 CGN	629	1,113
2 FFG	440	779
1 AOE	630	1,115
TOTAL	9,106	16,117

WASTE PROCESSING AND HANDLING STRATEGY

- Operational Concept--Generating Ship
  - Minimize space and manpower requirements
  - Trash compaction near source
    - galleys
    - work sites
    - berthing areas

  - No other pre-processing
  - Stow compacted waste in tri-walls (4ft x 4ft x 4ft)
  - Transfer waste during ship refueling

WASTE PROCESSING AND HANDLING STRATEGY

- Operational Concept --Processing Ship
    - Waste storage and processing areas(s)
        - Volume of compacted waste
        - Battle group generation rate
        - Replenishment Schedule
    - Preprocessing areas close to treatment units

PROCESSING CHAMBER FEEDER

- **Design Considerations**
  - Minimize preprocessing requirements
  - Minimize material handling requirements
  - Minimize personnel requirements
  - Ensure safety

- **Proposed Design**
  - Enclosed shredder with a positive displacement auger into the processing chamber
  - Located near processing ship receiving stations
  - Loading stations are interlocked to prevent processing chamber blowback
  - Maintenance doors are interlocked to shredder to prevent accidental starting

PRIMARY CHAMBER

- Design Considerations
  - Minimize weight
  - Able to tolerate ships rock and pitch
  - Able to withstand impact shock
  - Minimize particulate carryover
  - Increase energy efficiency

- Proposed Design
  - Utilizes an angled torch design to minimize height
  - Angled torch increases maintainability
  - Eliminates moving mechanisms in the primary zone
  - Light weight wall minimizes weight
  - Ceramic arrestor minimizes particulate carryover

SECONDARY COMBUSTION CHAMBER

- **Design Considerations**
  - Ensure organic destruction
  - Minimize weight
  - Able to tolerate ships rock and pitch
  - Able to withstand impact shock
  - Increase energy efficiency

- **Proposed Design**
  - Light weight wall minimizes weight
  - Sized to ensure complete combustion
  - Auxiliary plasma torch installed to provide supplemental heat

PLASMA TORCHES AND POWER SUPPLIES

Plasma Torches

- Design Considerations
  - Easily maintainable with limited trained crew
  - Long life electrode to ensure reliability
  - Minimize height
- Proposed Design
  - Angled design minimizes height
  - Replaceable front torch assembly is easily replaceable
  - Dual mode operation for easy start-up

Plasma Power Supplies

- Design Considerations
  - Reliable with ships provided power
  - Low EMF
- Proposed Design
  - Utilizes Navy Standard Magnetek power supplies to conform with EMF requirements

SLAG CRUCIBLE

- Design Considerations
  - Able to tolerate ships rock and pitch
  - Minimize water contact with slag
  - Facilitate easy pouring of slag
  - Able to withstand corrosive slag attack

- Proposed Design
  - Air cooled design eliminates possibility of slag in contact with cooling water
  - Integrated crucible and primary chamber is tolerant of ships rock and pitch
  - Installed induction plug controls pouring regardless of slag characteristics
  - Refractory is eliminated in contact with corrosive slag

SLAG HANDLING

- Design Considerations

  - Personnel safety
  - Labor requirements
  - Material handling requirements
  - Storage while awaiting off loading

- Proposed Design

  -Utilizes small ingots

  Eliminates possibility of contact with hot slag
  Easily moved by personnel
  Easily stacked and moved with existing material handling equipment

OFFGAS SYSTEM

- Design Considerations
  - Low infrared signature
  - Ensure environmental excellence
  - Minimize secondary waste streams

- Proposed Design

  Utilizes proven technology for environmental compliance

  Quench
  - Operated at 350 °F to keep moisture in gas phase

  Bag Filtration
  - Mechanically scrubs particulates

  Induced Draft Blower
  - Maintains system at a negative pressure

  Continuous Emissions Monitor
  - Used to assure environmental excellence
  - Assists in operations

Auxiliary Systems

- Design Considerations
  - Minimize components
  - Use existing ships systems
  - Use ships byproducts

- Proposed Design
  - Combustion Air Blower
    Supplies designated combustion air

  - Reverse Osmosis System
  - Supplies fresh water source to quench system
    Uses ships grey water to minimize waste stream

- Sea Water Source
  - Used to remove heat from system
    Titanium heat exchangers are used to minimize weight and corrosion

CONTROL STRATEGY

- Design Considerations
  - Clearly report important information
  - Operator staff will receive limited training

- Proposed Design
  - Automates torch, slag pouring, and temperature control functions
  - Utilizes standard PLC technology for maintainability
  - Heavy use of interlocks to maintain safe operations

SHIP INTEGRATION

Component Weights

	Dry Weight (lb)	Wet Weight (lb)
Primary Chamber	11,210	15,980
Slag System	2,450	2,700
SCC	4,815	4,990
Feeder	1,750	1,750
Offgas System	5,005	5,005
Controls	1,600	1,600
Auxiliary Systems	6,975	8,655
Total Weight	33,805	40,680

SHIP SELECTION

Ship Class	Station Ship	Embarked Helo	Electrical Capacity	Space with Flush Deck Access	Materials Handling Equipment
AE	No note 1	Yes	No	Yes note 2	Yes
T-AFS	No	Yes	Yes	Yes note 2	Yes
AO 177 T-AO 187	No note 1	No	Yes	Yes note 3	Yes
AOE	Yes	Yes	Yes	Yes	Yes

Note *1: Designated as shuttle ship when AOE is assigned. When an AE/AO combination replaces the AOE the AO operates as a station ship. Both the AE and AO lack the maneuvering speed to stay with the CVBG during flight operations and high speed transits.*
Note 2: Diminishes cargo capacity.
Note 3: Requires construction of cargo deck structure to house PAWDS unit. Available internal space currently being reconfigured for plastic compaction and storage.

OPTIONAL SHIP INSTALLATIONS

- AIRCRAFT CARRIER
- LARGE AMPHIBIOUS SHIPS
- AO/T-AO
- LST CLASS CONVERSION
- HOSPITAL SHIP

SUMMARY OF UNIQUE SYSTEM FEATURES

- High performance lightweight wall design
- Angled Torch
- Air-cooled Metal Crucible
- Crucible Induction Plug
- Contained Cooling Mechanism
- Ceramic Arrestor

SUMMARY OF DESIGN TARGET OBJECTIVES

- Design based on past operations experience
- Energy efficient light weight design
- Space efficient design utilizing existing ship systems
- Adaptable to all shipboard waste streams
- Helps minimize existing grey water waste streams
- Provides a final treated solution to waste problem
- Design ready for construction with little R&D effort

Session 4 - Supercritical Water Oxidation Technologies

Chairman: Jean-Roger Guichard,
Compagnie Européenne d`Etudes en Environnement Industriel - C3EI, France

Overview of Technologies Using Sub- or Supercritical Water Oxidation

TECHNOLOGIES USING SUB OR SUPERCRITICAL WATER OXYDATION

ZIMPRO

SUBCRITICAL

T°:	350°C
P :	150 bar
Oxidant :	Air

100 units in USA and Japan.

MODAR

SUPERCRITICAL

Recirculation
Horizontal or vertical reactor

T° :	600°C
P :	225 bars
O :	Air or O_2

Several units in USA and Japan.

CIBA-CEIGY

SUBCRITICAL

2 Reactors serial type h=30 m

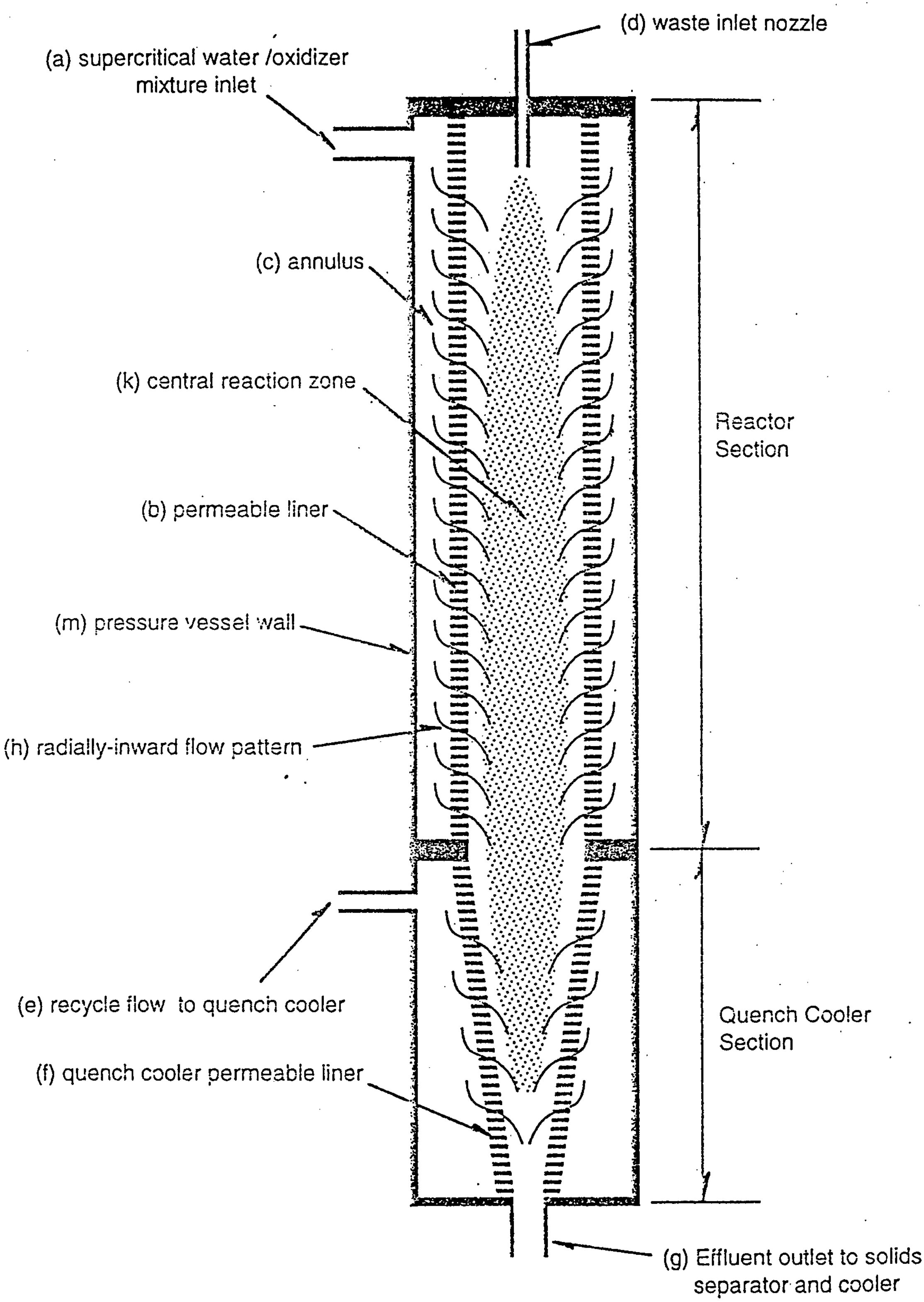
3 operating units : 2 in Switzerland and 1 in Germany.

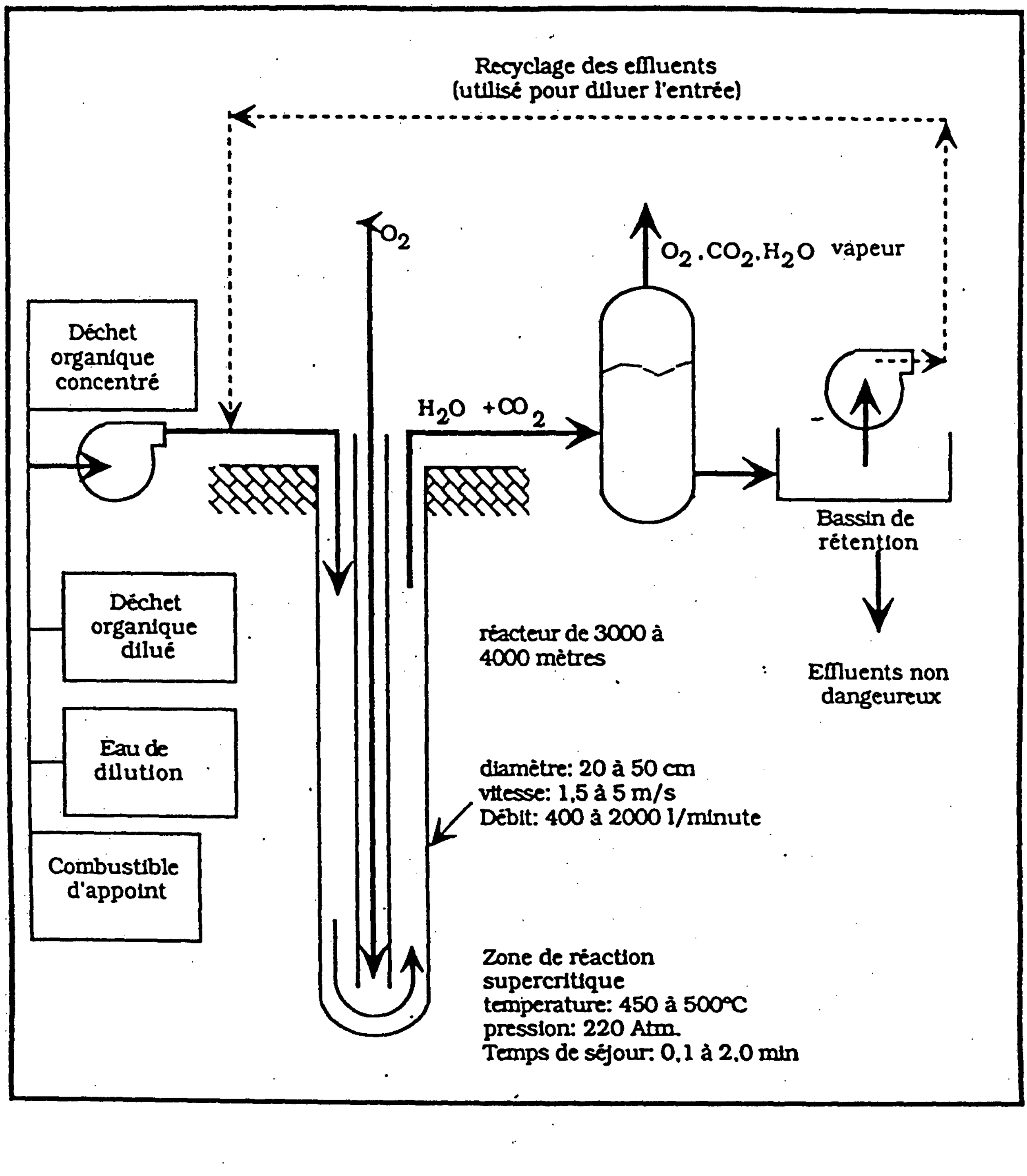
BAYER

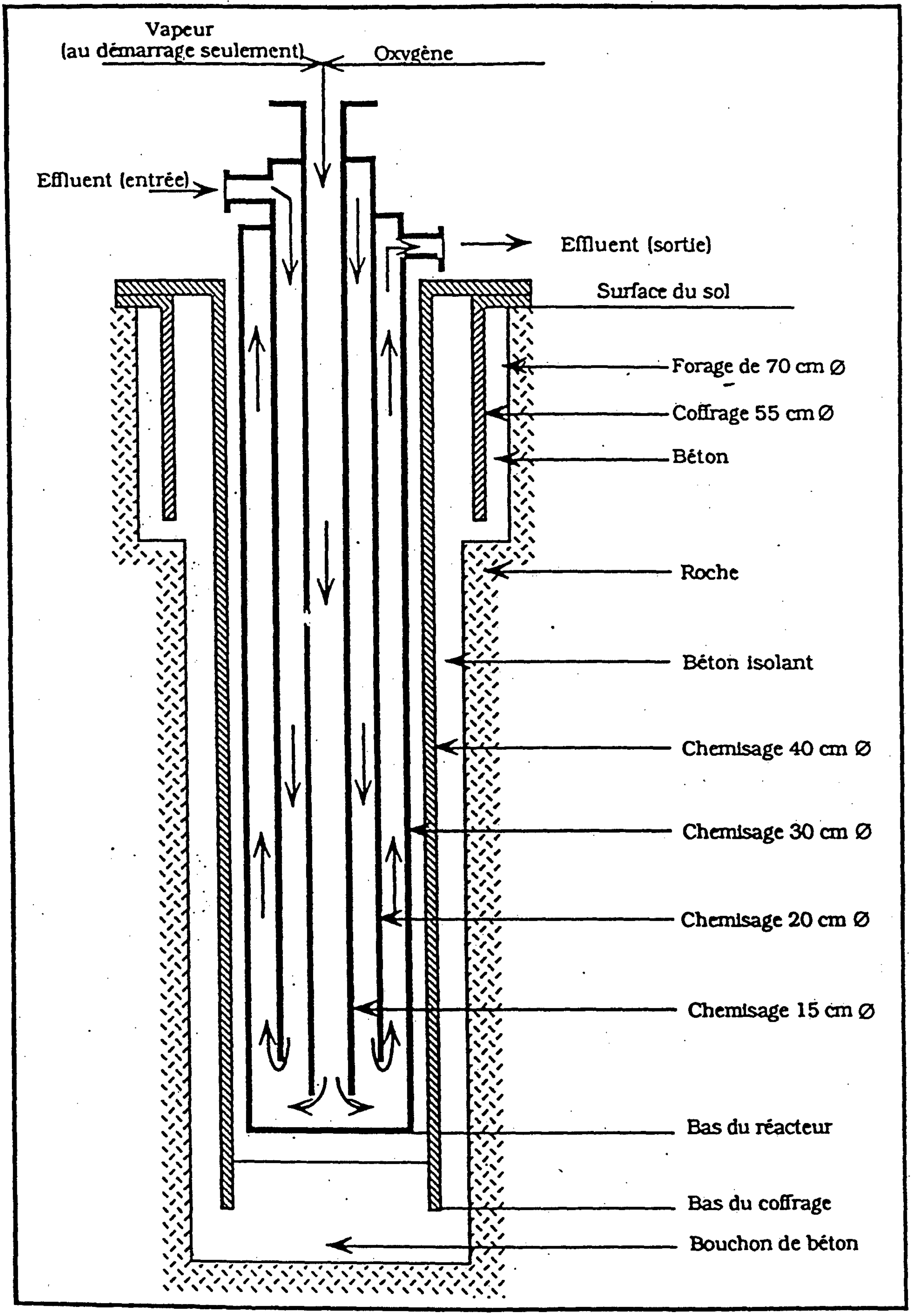
A low capacity pilot, low efficiency.

ECOWASTE	SUPERCRITICAL		
	Tubular tube		
	T° :	500°C	
	P :	250 bars	
	O :	O_2	
A low capacity pilot (40l/h).			
BATTELLE	Double chamber in equipressure.		
FOSTER WHEELER DEVELOPMENT	Transpiring wall		
SUMMIT RESEARCH	Transpiring wall		
WETOX	Horizontal reactor		
	T° :	250°C	
	P :	40 bars	
	O :	Air	
Only one operation.			
VERTECH Treatment System	Long tube vertical type reactor.		
	T° :	260°C	
	P :	100 bars	
	(hydrostatic pressure)		
	O :	Air or O_2	
BURLESON (Cf. VERTECH)	Horizontal reactor in a 4000 m deep pit		
	T° :	450°C	
	P :	150 bars	
	(hydrostatic pressure)		
	O :	Air or O_2	

General Arrangement of the SRCTranspiring Wall SCWO Reactor




Recyclage des effluents
(utilisé pour diluer l'entrée)
O_2
$O_2.CO_2.H_2O$ vapeur
Déchet organique concentré
H_2O $+CO_2$
Bassin de rétention
Déchet organique dilué
réacteur de 3000 à 4000 mètres
Effluents non dangeureux
Eau de dilution
diamètre: 20 à 50 cm
vitesse: 1,5 à 5 m/s
Débit: 400 à 2000 l/minute
Combustible d'appoint
Zone de réaction supercritique
temperature: 450 à 500°C
pression: 220 Atm.
Temps de séjour: 0,1 à 2,0 min


Vapeur
(au démarrage seulement)
Oxygène
Effluent (entrée)
Effluent (sortie)
Surface du sol
Forage de 70 cm Ø
Coffrage 55 cm Ø
Béton
Roche
Béton isolant
Chemisage 40 cm Ø
Chemisage 30 cm Ø
Chemisage 20 cm Ø
Chemisage 15 cm Ø
Bas du réacteur
Bas du coffrage
Bouchon de béton

HYDROTHERMAL APPLICATIONS

1 - **NKT** (Danish Company) Pulsed reactor type - long tube - co-current operation

2 - **UNIROYAL Chemicals** (Canada) Hazardous waste treatement in subcritical

3 - **Eastman Fine Chemicals** (England) in operation since 93 effluent after paracetamol synthesis

4 - **BASF A.G.** (Germany) subcritical process - no information

5 - **Institute of Process Engineering** (Switzerland) specific waste 7 Kg/H and cryogenics

6 - **University of Valladolid** (Spain) industrial prototype 40 l/h

7 - **MITI** (Japan) urban and industrial waste, 2 m^3/j, 94-97

HYDROTHERMAL APPLICATIONS

8 - France :

- CEA Pierrelate	Specific waste	1 Kg/H - in operation since 95
- CEA Cadarache	Specific waste	1 Kg/H - in operation since 95
- CNRS - ICMCB	Industrial waste	1 Kg/H - in operation since 95
- CNES - C3EI	Subcritical Batch and/or automatic operation industrial waste, 0,45 l/H - in operation since 94	
- CNES - C3EI	6 Kg/H, automatic operation industrial waste - in operation since 97	

9 - USA :

- Eco Waste Technology	Urban waste	3,5 m³/j	- 90-94
- Idaho National Enginneering Laboratory (DOE)		3 m³/j	- 90-94
- General Atomic	Military	5 m³/j	- 91-96 (1M$)
DOE / ARAP	Military	5 m³/j	- 95-97 (22m$)
- US Army (double chamber)	Military	10 m³/j	- 95-97

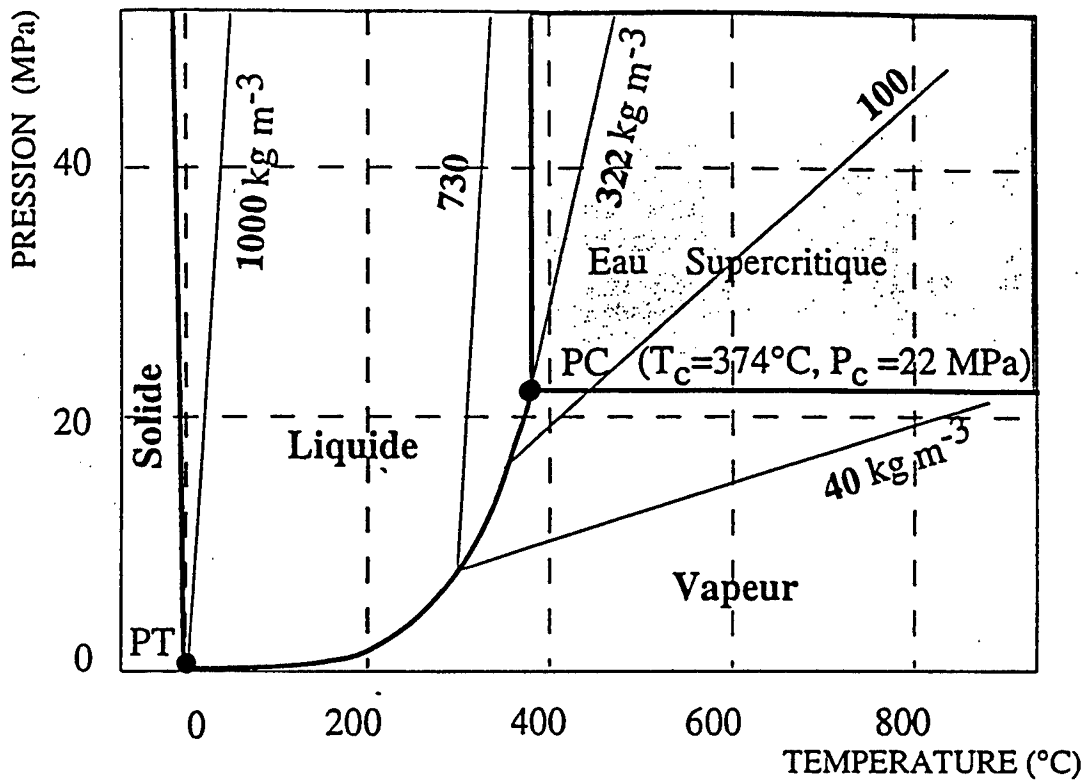


Figure 1 : Diagramme Pression - température de l'eau

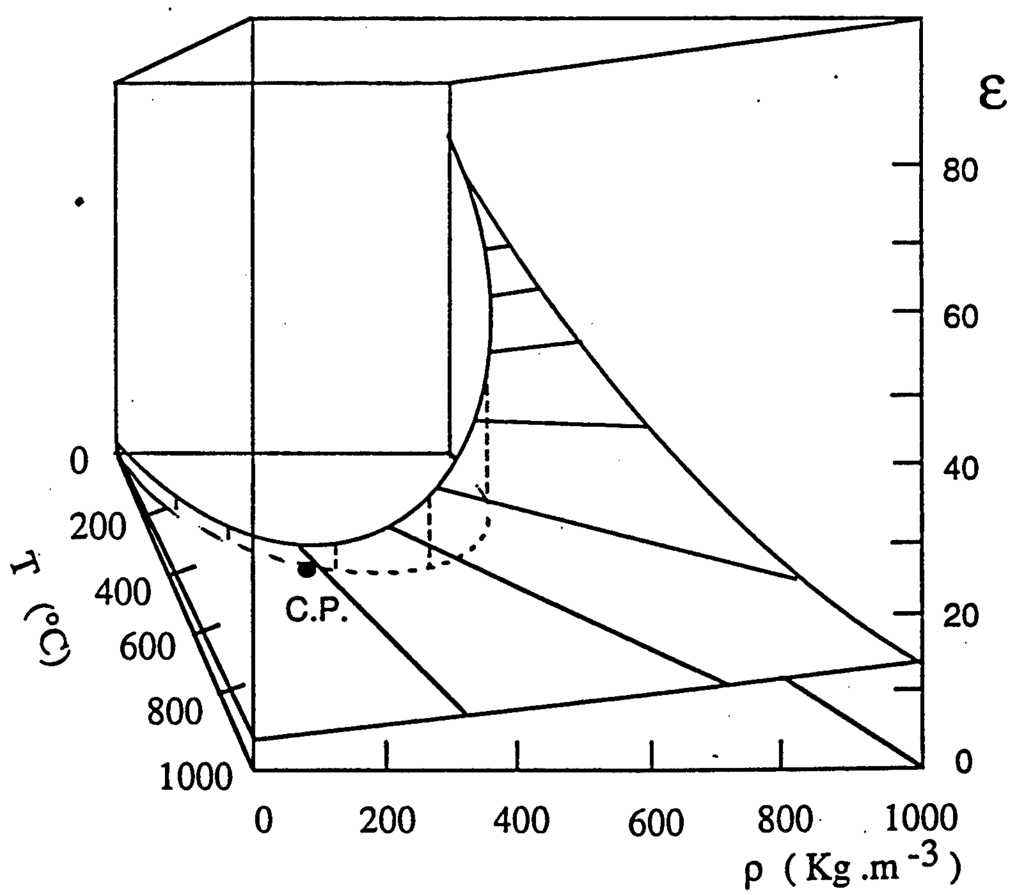
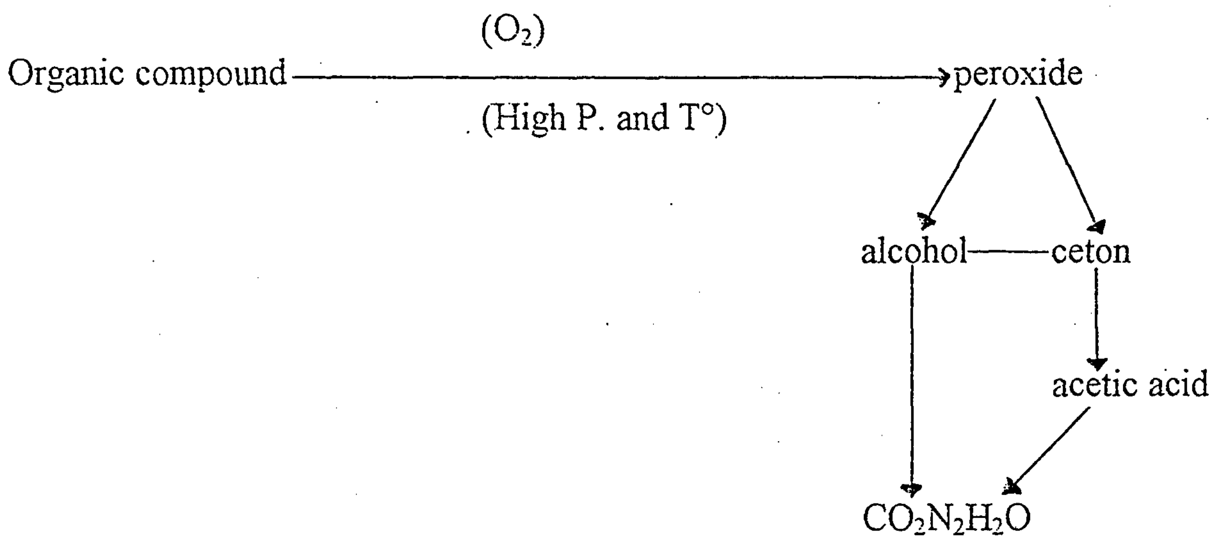


Figure 2 : Représentation de l'évolution de la permittivité diélectrique de l'eau en fonction de la température et de la masse volumique.

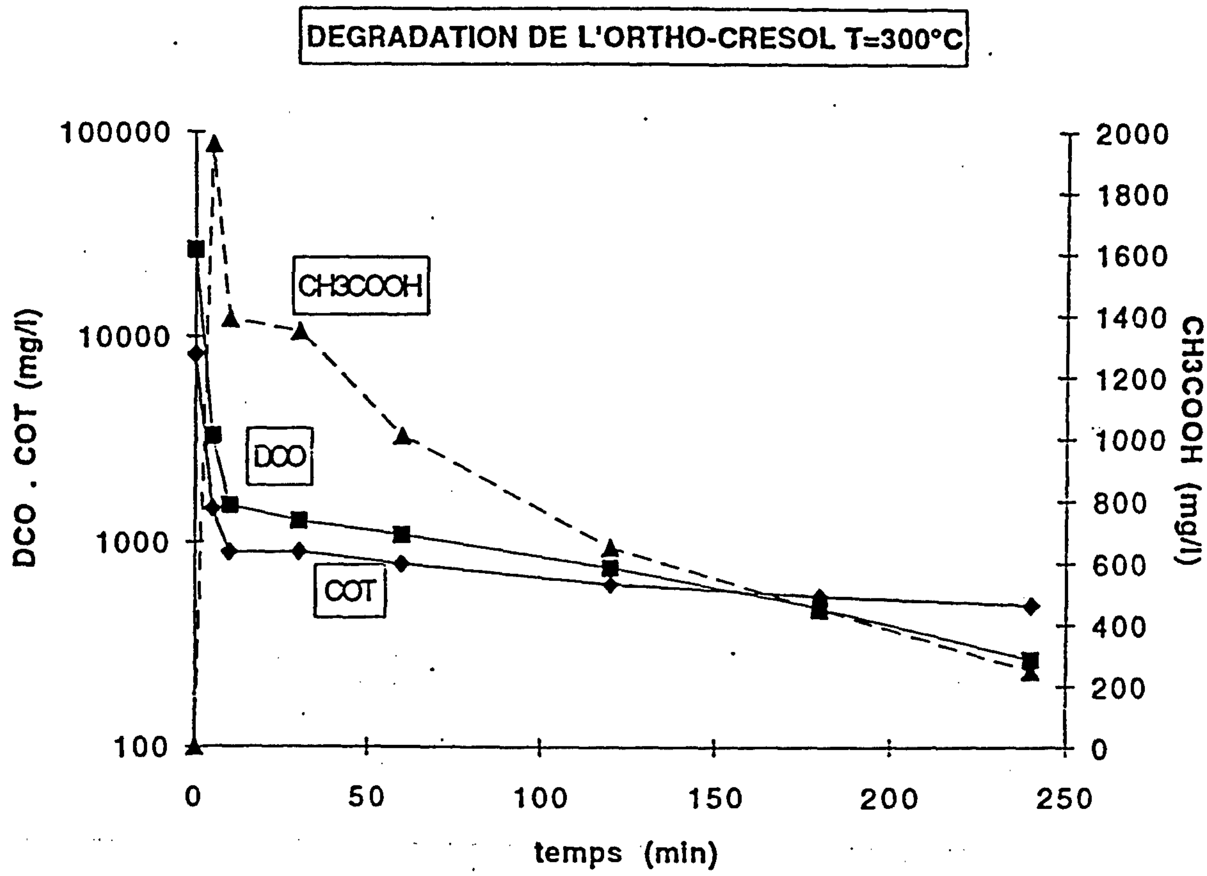
OXYDATION PROCESS STUDY OF MOLECULE TYPE

REACTION DIAGRAM

The oxidation reaction diagram in liquid phase of an organic compound is hereunder specified.



tig.-4


DEGRADATION DE L'ORTHO-CRESOL T=300°C
100000
10000
1000
100
DCO . COT (mg/l)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
CH3COOH (mg/l)
CH3COOH
DCO
COT
0
50
100
150
200
250
temps (min)

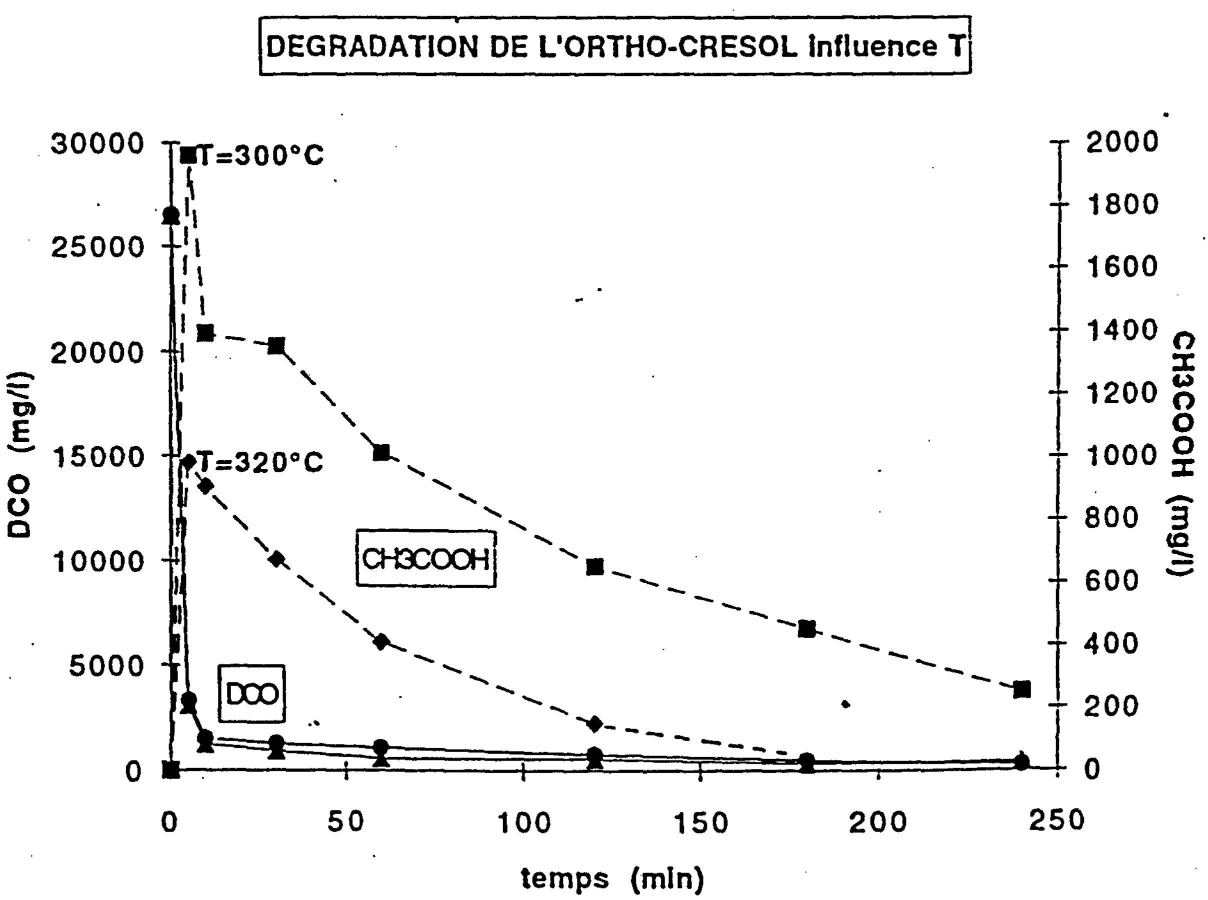
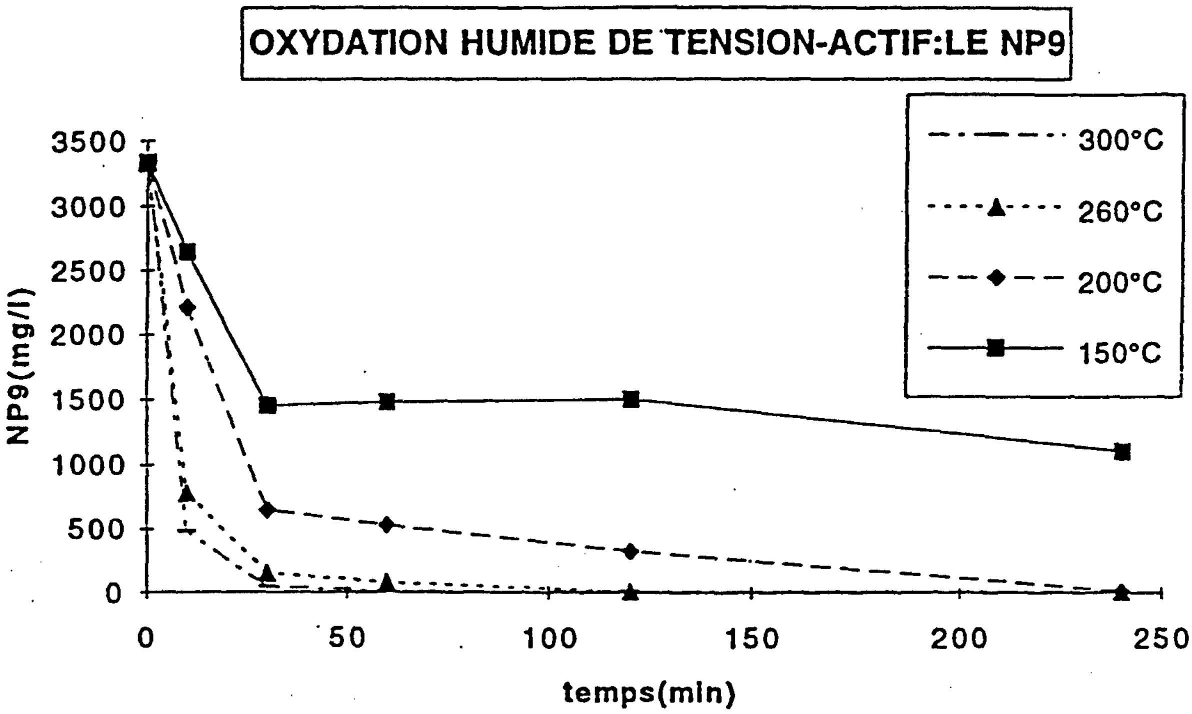

DEGRADATION DE L'ORTHO-CRESOL Influence T
30000
25000
20000
15000
10000
5000
0
DCO (mg/l)
T=300°C
T=320°C
CH3COOH
DCO
2000
1800
1600
1400
1200
1000
800
600
400
200
0
CH3COOH (mg/l)
0
50
100
150
200
250
temps (min)

fig.5

fig.16


OXYDATION HUMIDE DE TENSION-ACTIF:LE NP9
300°C
260°C
200°C
150°C
NP9(mg/l)
3500
3000
2500
2000
1500
1000
500
0
0
50
100
150
200
250
temps(min)

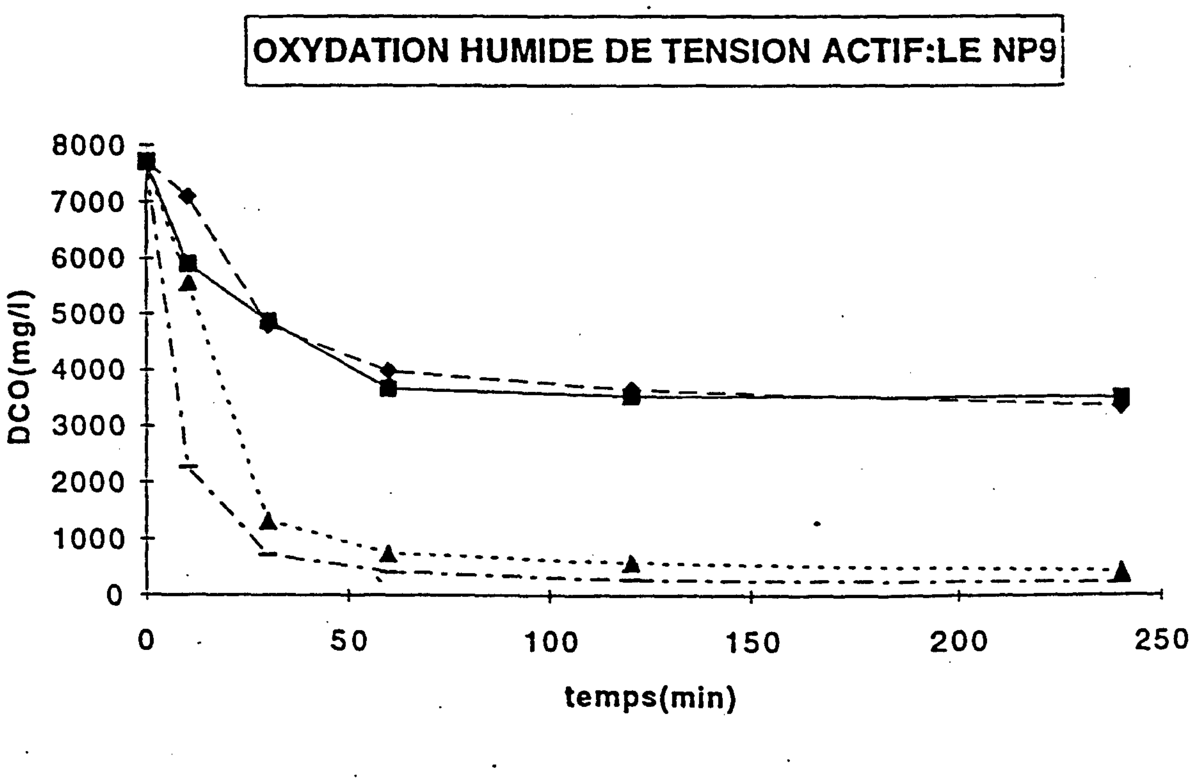
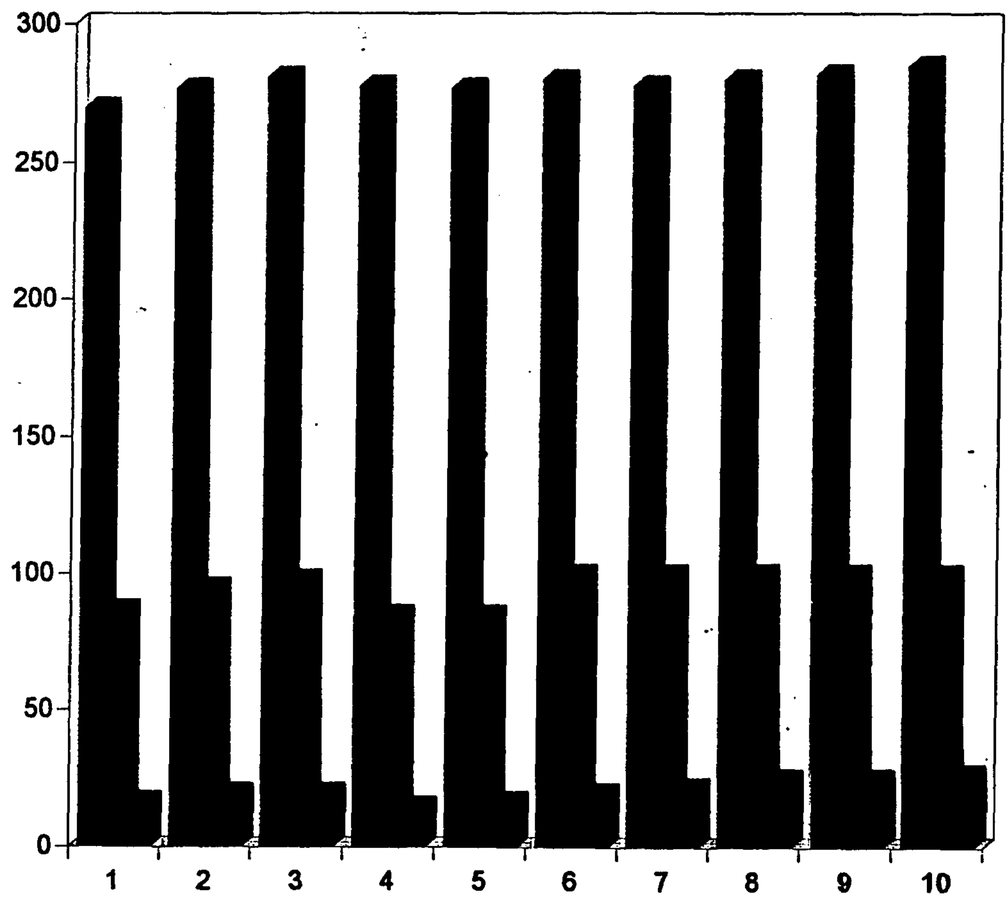

OXYDATION HUMIDE DE TENSION ACTIF:LE NP9
DCO(mg/l)
8000
7000
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250
temps(min)

fig.17

1	SACS PLASTIQUES (PE + PEP)	270	87	17
2	BOITES PLASTIQUES (PP+PET+P5)	277	95	20
3	BOUTEILLES PLASTIQUES (PE+PET+PVC)	281	98	20
4	CELLULOSE MICROCRISTALLINE	278	85	15
5	PAPIER JOURNAL	277	85	17
6	COTON	280	100	20
7	BOIS (SCIURE)	278	100	22
8	BOIS (FIBRES)	280	100	25
9	CAOUTCHOUC	282	100	25
10	CUIR	285	100	27



Températures et Pressions assurant une liquéfaction des solides organiques en 1 Heure

Table II. **Chemicals Successfully Treated by Supercritical Water Oxidation and Typical Destruction Efficiencies (continued)**

Organic Compound	*Bench-Scale*	*Pilot-Scale*	*Destruction Efficiency*[b], %
Mercaptans	x		
Methanol	x	x	
Methyl Cellosolve	x		
Methylene Chloride	x	x	
Methyl Ethyl Ketone	x		99.993
Nitrobenzene		x	>99.998[c]
2-Nitrophenol	x		
4-Nitrophenol	x		
Nitrotoluene	x		
Octachlorostyrene	x		
Octadecanoic Acid Magnesium Salt	x		
Pentachlorobenzene	x		
Pentachlorobenzonitrile	x		
Pentachloropyridine	x		
Phenol	x		
Sodium Hexanoate	x		
Sodium Propionate	x		
Sucrose	x		
Tetrachlorobenzene	x		
Tetrachloroethylene	x	x	99.99
Tetrapropylene H	x		
Toluene	x		
Tributyl Phosphate	x		
Trichlorobenzenes	x		99.99
1,1,1-Trichloroethane	x	x	>99.99997[c]
1,1,2-Trichloroethane		x	>99.981[c]
Trichloroethylene	x		
Trichlorophenol	x		
Trifluoroacetic Acid	x		
1,3,7-Trimethylxanthine	x		
Urea	x		
o-Xylene	x		99.93

Continued on next page

<u>Session</u> 4 - Supercritical Water Oxidation Technologies

SCWO Process Development at Forschungszentrum Karlsruhe

by Dr. Helmut Schmieder,
Forschungszentrum Karlsruhe, Germany

Forschungszentrum Karlsruhe
Technik und Umwelt

INSTITUT FOR TECHNICAL CHEMISTRY

Department of the Research Centre Karlsruhe financed by the Federal Government and the State of Baden-Württemberg

OBJECTIVE

Transfer of Process Developments to Industrial Applications

US-Europ. Workshop, Oct. 28-31 1997 SCHMIEDER, FZK-ITC

TASK: CLEANER TECHNOLOGY

PROCESS DEVELOPMENT UP TO PILOT SCALE

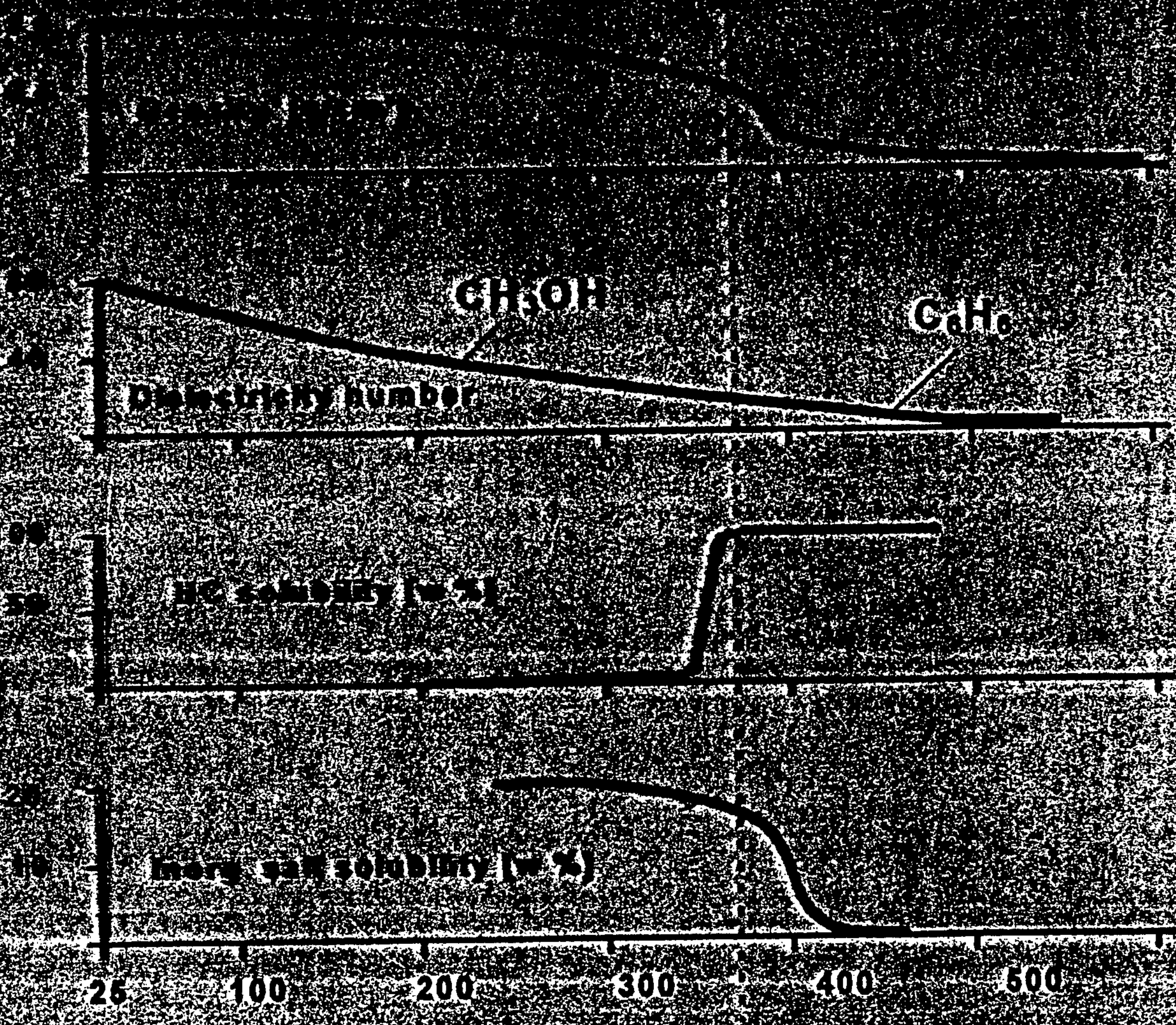
- Syntheses with and in CO_2. Catalyst development.
  - Substitution of problematic C_1 building blocks
  - Substitutions of problematic solvents
- Supercritical Separation Processes
  - deoiling of metal-working residues by s-CO_2
  - surface cleaning (small parts, electronics etc.) by s-CO_2
- Supercritical Water Chemistry
  - SUPERCRITICAL WATER OXIDATION
  - Conversion of biomass (org. waste, wood etc.) for energetic and chemical use and syntheses
- Research for advanced incineration and gasification
- Electrochemical development
  - pollutant (highly chlorinated organics, warfare agents etc.) destruction by electrochemical oxidation mediators
  - screening for organic electrosyntheses

„SCWO PROCESS DEVELOPMENT AT FORSCHUNGSZENTRUM KARLSRUHE“

H. Schmieder

CONTENT

- Introduction
- Lab-scale plant: results with model substances
- Bench-scale: results with real waste
- Corrosion
- Costs?
- Summary

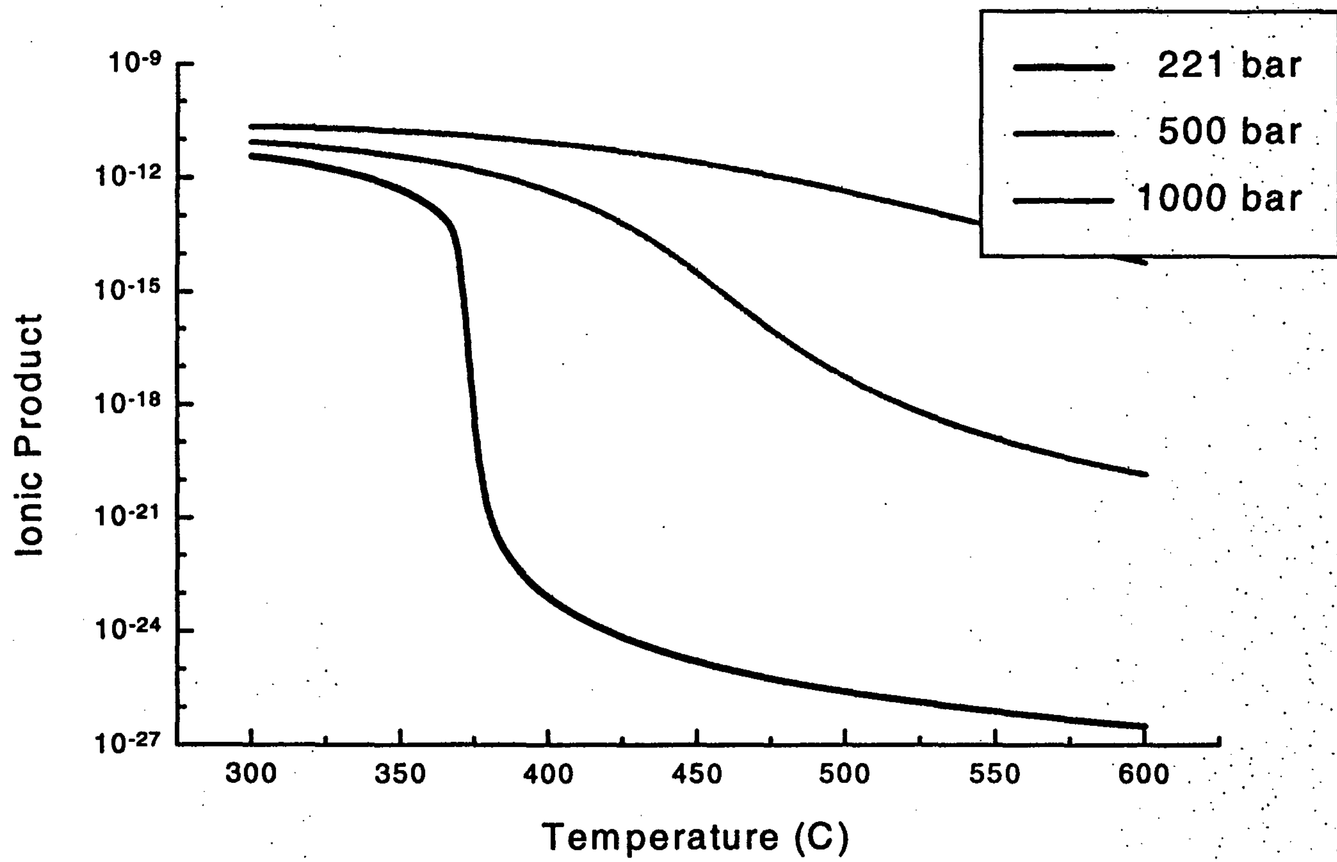


Properties of water at 250 bar

- High solubility for organic compounds and gases
  → homogeneous reaction system

- Low inorganic solubility
  → salts precipitate

Ionic product of water as a function of temperature at different pressures



S C W O

HIGH POTENTIAL

- Complete Oxidation with high space-time-yield
- Low temperature incineration >> no NO/NO_2
- Cl, S, P form acids/salts
- Expensive off-gas cleaning avoided
- Efficient heat recovery possible
- CO_2 can be easily separated

STATE OF THE ART

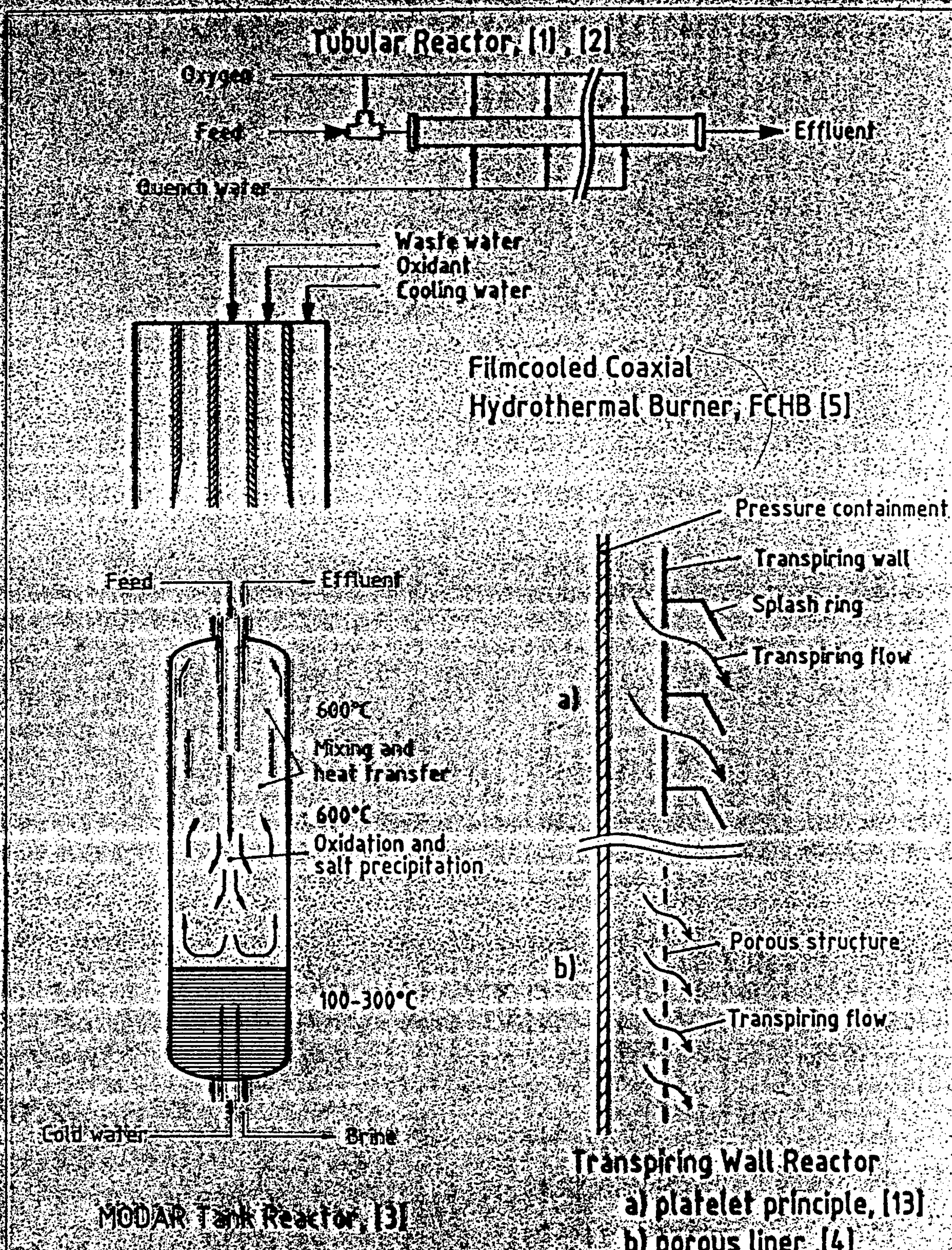
Commercial plant (EWT, USA) in operation but only unproblematic waste treated: no salts and no chlorine.
Pilot and demonstration plants designed by companies (GA etc.).

R & D:

USA - National Labs and several Universities.

Europe - C.E.A. and Universities in F; FZK, FhG and Universities in D.

Japan - Companies and Universities.



Principles of the most outstanding SCWO reactor configurations

S C W O

POSSIBLE CLIENTS

- **Municipal and industrial sewage**
- **Aqueous effluents**
  paper industry
  chemical industry
  pharmaceutical industry
- **Warfare agents, explosives, nuclear mixed waste**
- **......**

Problems

Corrosion by higher chlorine concentrations.....
Salt precipitation >> clogging
(Reliable high pressure feeding of suspensions)

Solution >> liner, reactor design

S C W O

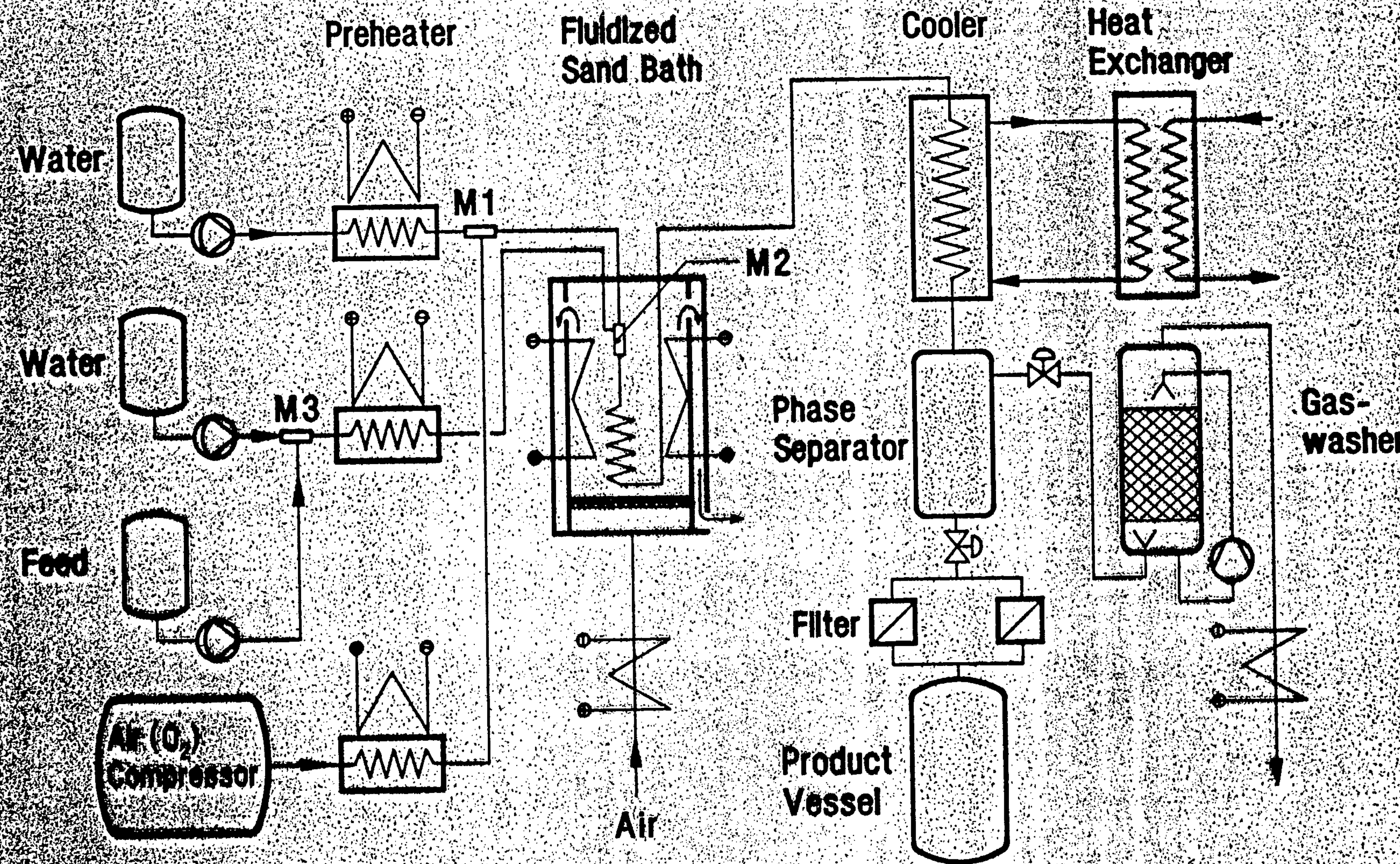
CURRENT EXPERIMENTS

- Continuous lab-scale, 1 kg H_2O/h

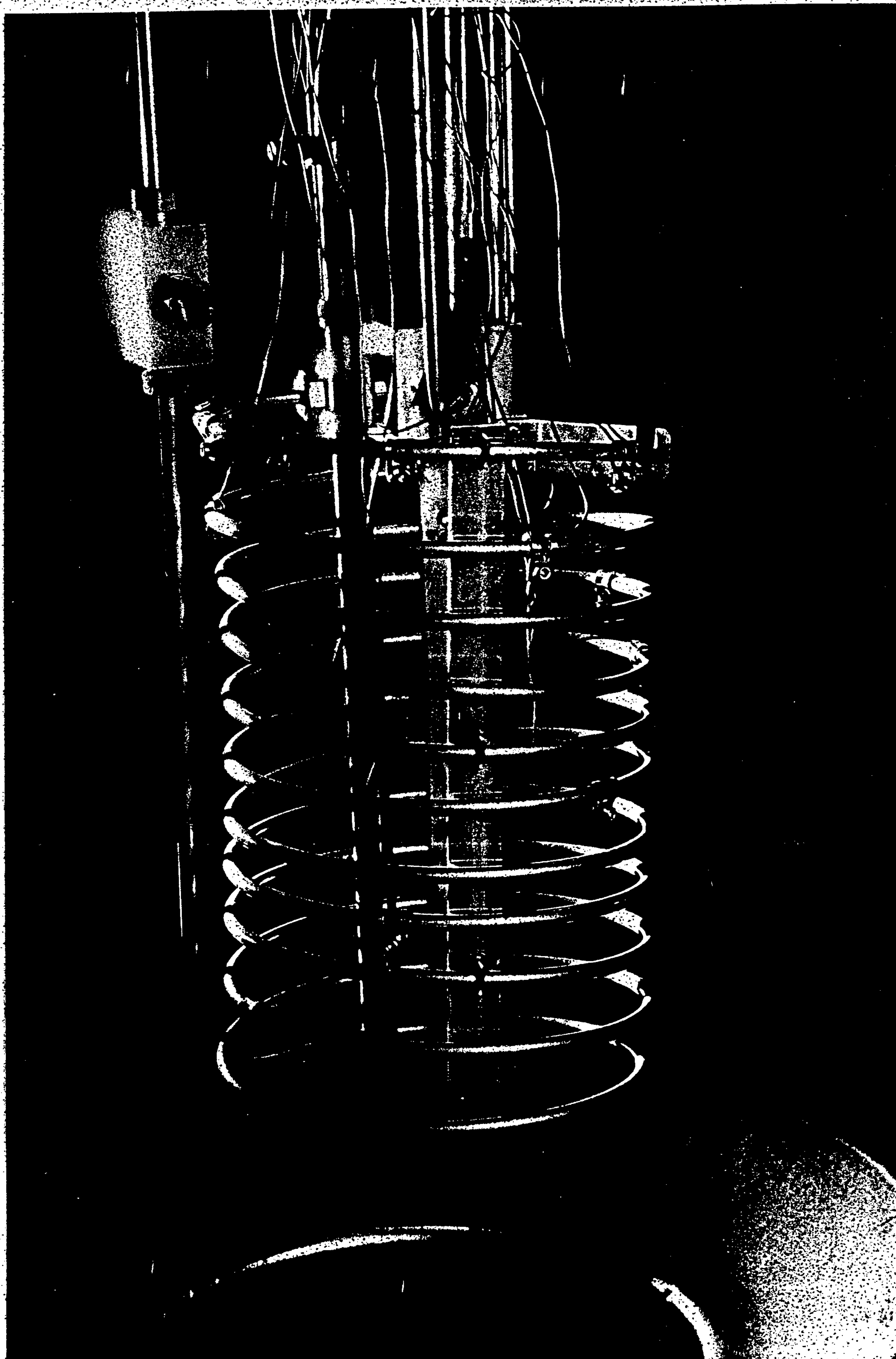
- Continuous bench-scale, 10-15 H_2O/h

- Corrosion test facility

Forschungszentrum Karlsruhe
Technik und Umwelt



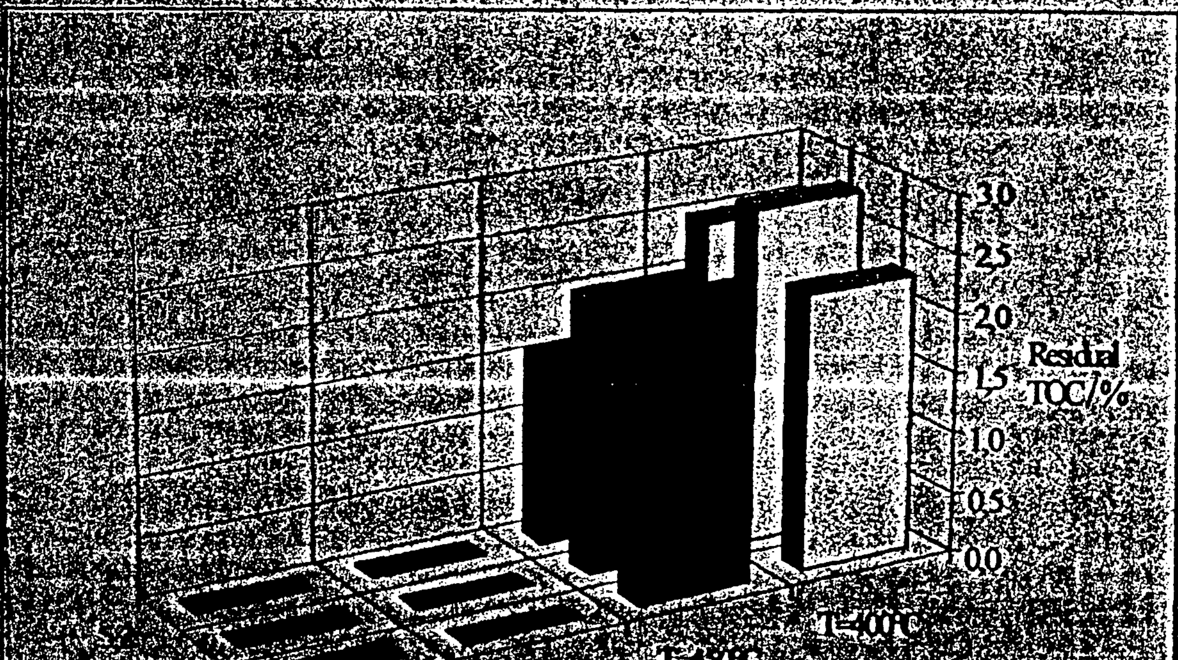
Bench Scale, ≤ 15 Kg H_2O/h



Residual TOC data for the oxidation of Toluene in the benchscale plant

Pressure 260 bar, Throughput of Water 10 kg/h, Concentration 3 w-%

Parameters are throughput of air (A) and temperature T



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Residual TOC data for the oxidation of nitrobenzene in the labscale plant

Pressure 240 bar, Temperature 550 °C

Parameters are throughput of water (W), air (A) and organic material (O)

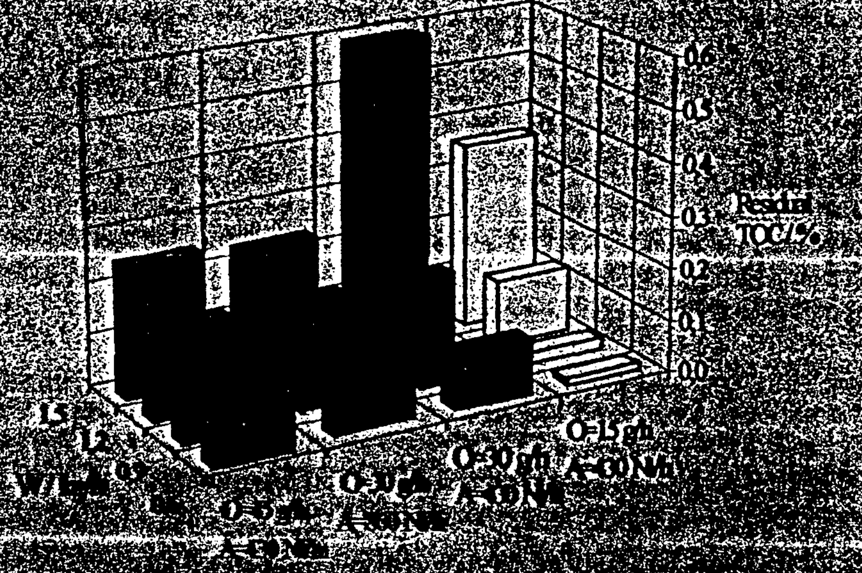


TABLE 7. DESTRUCTION EFFICIENCIES OF HAZARDOUS ORGANICS BY SUPERCRITICAL WATER OXIDATION

Class /Compound	Temperature (°C)	Residence Time (min)	Destruction Efficiency (%)	Reference
Organic Nitro Compounds				
2,4-Dinitrotoluene	457	0.5	99.7	Thomason, 1984
2,4-Dinitrotoluene	513	0.5	99.992	Thomason, 1984
2,4-Dinitrotoluene	574	0.5	99.9998	Thomason, 1984
Halogenated Aliphatics				
1,1,1-Trichloroethane	495	3.6	99.99	Modell, 1985 (2)
1,2-Ethylene dichloride	495	3.6	99.99	Modell, 1985 (2)
1,1,2,2-tetrachloroethylene	495	3.6	99.99	Modell, 1985 (2)
Halogenated Aromatics				
Hexachlorocyclopentadiene	488	3.5	99.99	Modell, 1985 (2)
o-chlorotoluene	495	3.6	99.99	Modell, 1985 (2)
1,2,4-Trichlorobenzene	495	3.6	99.99	Modell, 1985 (2)
4,4-Dichlorobiphenyl	500	4.4	99.993	Modell, 1985 (2)
DDT	505	3.7	99.997	Modell, 1985 (2)
PCB 1234	510	3.7	99.99	Modell, 1985 (2)
PCB 1254	510	3.7	99.99	Modell, 1985 (2)
Dioxin (2,3,7,8-TCDD)	574	3.7	99.99995*	

Destruction/reduction efficiency, DRE

M. Modell, DOE/CE/40914-T

FIGURE 13. TCDD AND TOC DESTRUCTION EFFICIENCIES FOR DIOXIN SOLUTION
(basis: 1 L of dioxin feed, as tested)

2, 3, 7, 8 –TCDD	=	
In feed, @ 0.5 mg /L	=	500,000,000 pg
In aqueous effluent, @ 264/pg liter	=	264 pg
Residual, % of feed = $(264/5 \times 10^8)*100$	=	0.00005%
TCDD destruction/reduction efficiency	=	<u>99.99995%</u>
TOC		
In feed, @ 14,100 ppm	=	14,100 ppm
In aqueous effluent, @ 18.1 ppm	=	<u>18 ppm</u>
Residual, % of feed residual + (18.1/14,100)*100	=	0.13%
TOC destruction efficiency	=	<u>99.87%</u>

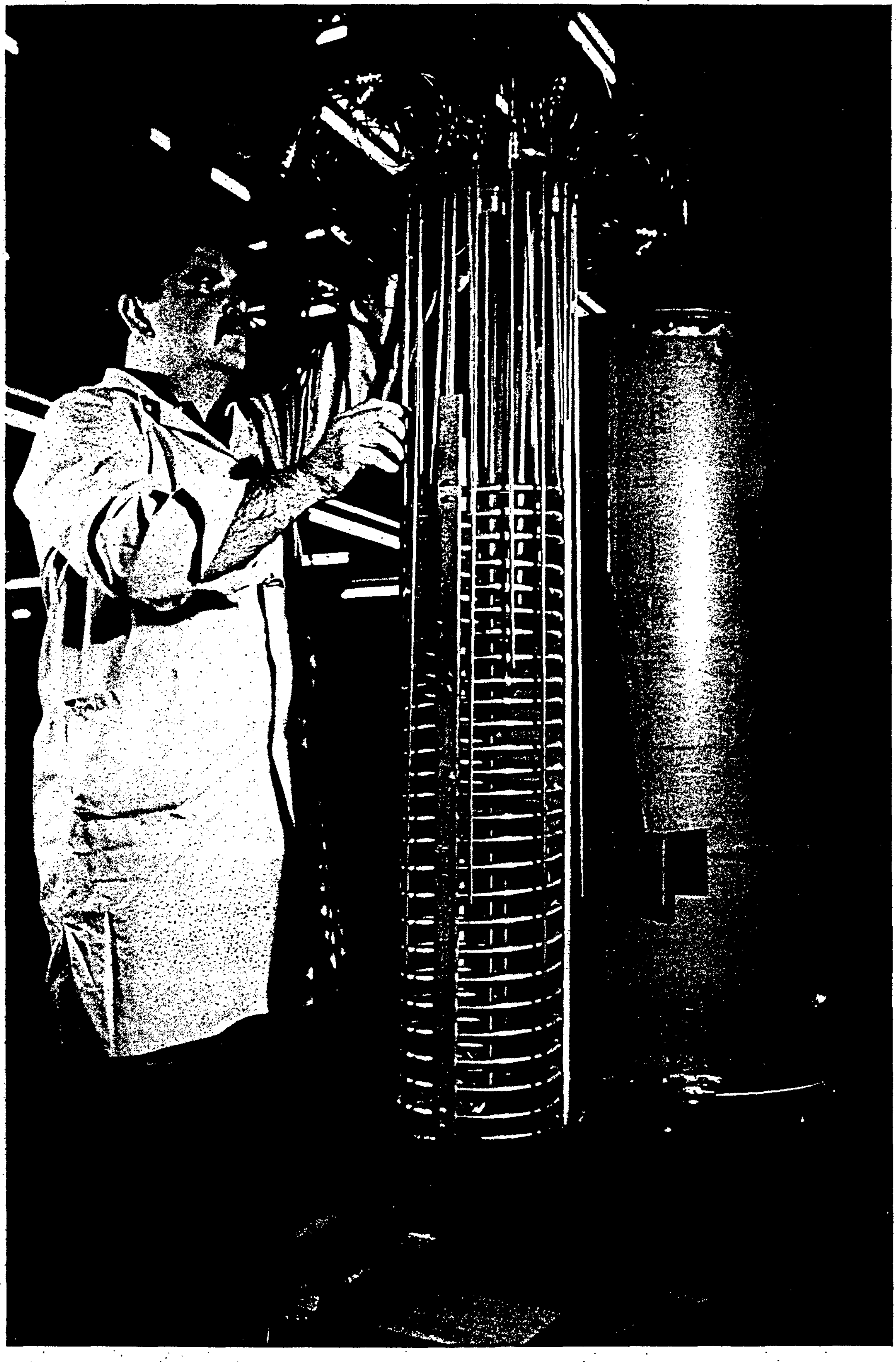
H. Modell, DOE/CE/40914-T1

TABLE 9. SCWO BENCH SCALE TESTS RESULTS

CONCENTRATION (mg/kg unless otherwise noted)

ANALYTICAL TEST	PULP MILL SLUDGE NCASI, 567 °C Sludge	Aqueous	Solids	Destruction (%)	PULP MILL SLUDGE Company X, 586 °C Sludge	Aqueous	Solids	Destruction (%)
Total solids	36,100	NA	4,300	88	43,900	NA	8,900	80
2, 3, 7, 8-TCDD (pg/g)	0.34	0.0031	1.9	96.7	123	ND(.02)	2.9	99.98
2, 3, 7, 8-TCDF (pg/g)	1.58	ND(.0027)	5.3	>98.4	834	ND(.01)	25.6	99.97
MAJOR ELEMENTS								
Carbon	12,043	27	18,500	99.1	16,362	16	11,000	99.3
Oxygen	11,545	NA	51,800	98.1	13,109	NA	35,600	97.6
Hydrogen	1,563	NA	10,250	97.2	1,664	NA	5,300	97.2
CHO - SUBTOTALS	25,151	27	80,550	98.5	31,134	16	51,900	98.5
	Sludge	Aqueous	Solids	Recovery (%)	Sludge	Aqueous	Solids	Recovery (%)
MINOR ELEMENTS								
Aluminum	132	5	63,600	211	281	7	36,100	117
Calcium	678	256	29,500	55	474	460	8,380	109
Chlorine	329	186	246	55	208	210	125	97
Iron	25	ND	3,590	61	229	0	18,000	70
Magnesium	40	1	3,240	37	32	3	2,320	74
Manganese	20	1	1,440	34	6	0	355	66
Nitrogen	217	187	148	64	145	18	187	13
Phosphorus	17	1	10	8	25	1	186	10
Potassium	ND	8.7	2,270		ND	12	1,900	
Silicon	40	73	196	181	74	160	867	218
Sodium	146	103	9,960	97	68	77	2,090	137
Sulphur	159	105	0	64	417	413	2	95
MINOR - SUBTOTALS	1,803	927	114,199	77	1,958	1,363	70,512	99
Distribution		50%	27%			67%	32%	
TRACE ELEMENTS								
Arsenic	ND	0.008	ND		0.24	0.019	37	145
Barium	2	0.21	147	44	ND	0.06	210	
Boron	ND	0.31	1.6		ND	0.22	1.4	
Cadmium	ND	ND	0.4		ND	0.01	1.0	
Chromium	1.0	0.89	206	177	4.5	0.11	355	73
Copper	1.4	0.06	59	22	1.6	0.39	100	79
Lead	ND	ND	20		ND	ND	27	
Mercury	ND	ND	0.60		0.01	0.0023	0.70	84
Nickel	1.8	0.05	182	46	2.3	0.40	410	175
Selenium	ND	ND	ND		ND	0.01	1.9	
Silver	ND	ND	1.1		0.08	ND	2.1	23
Strontium	1.0	0.31	62	57	0.9	0.90	40	136
Zinc	5.8	0.26	296	26	7.2	0.55	488	68
TRACE - SUBTOTALS	13	2	975	48	17	3	1,674	104
Distribution		16%	33%			15%	89%	

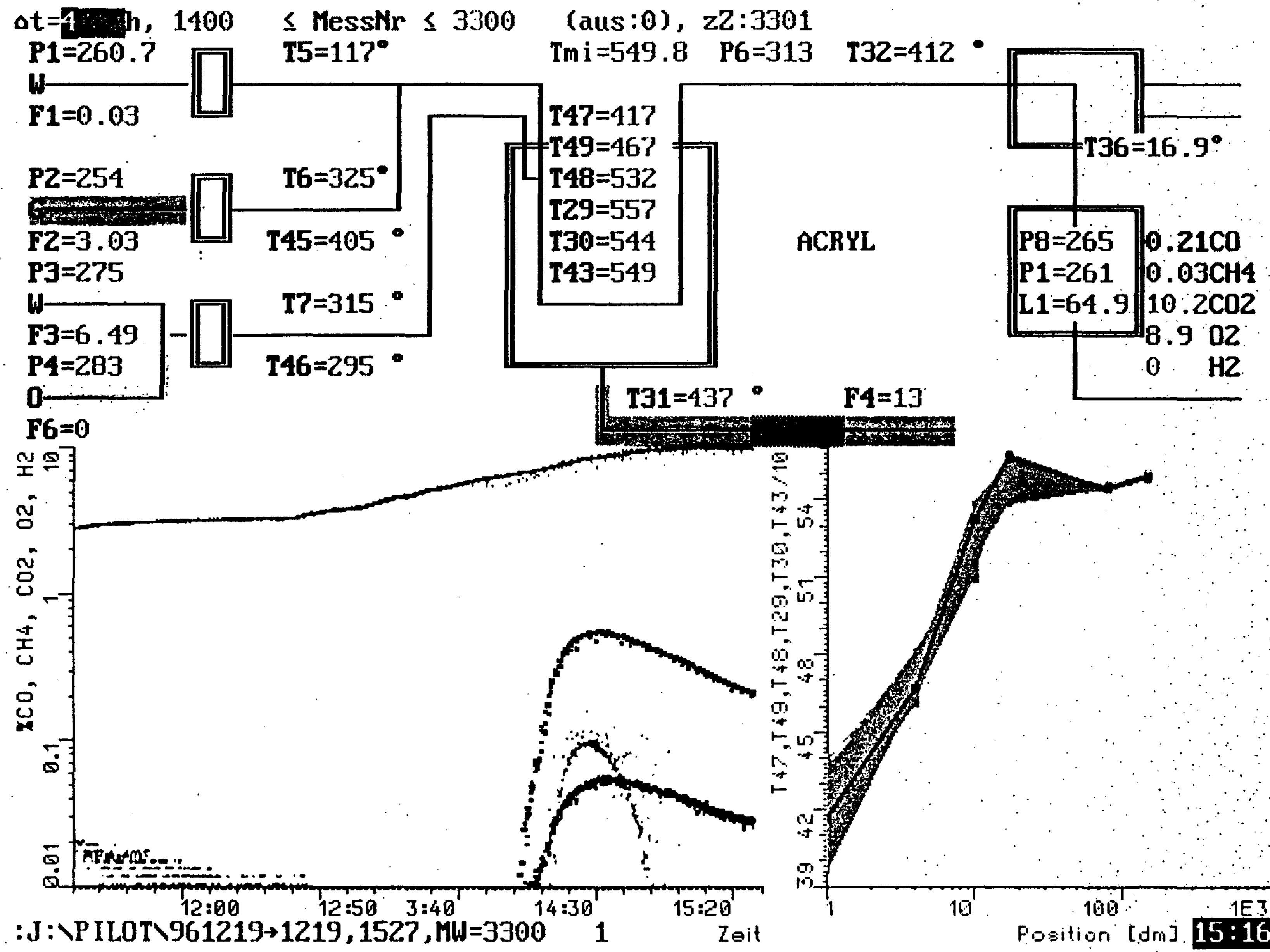
M. Modell, DOE/CE/40914-T?



TUBULAR REACTOR OF BENCH SCALE (14000 mm, i.d. 8 mm)

Origin	Feed-TOC ppm	TOC Decomposition, %	Temperature °C	Salt Content %	Solids	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Paper Industry	2.000	98	450	0,1	+	[redacted]
	2.000	99	500	0,1	+	
	11.000	97	500	0,2	+	
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

BENCH SCALE EXPERIMENTS WITH REAL WASTES



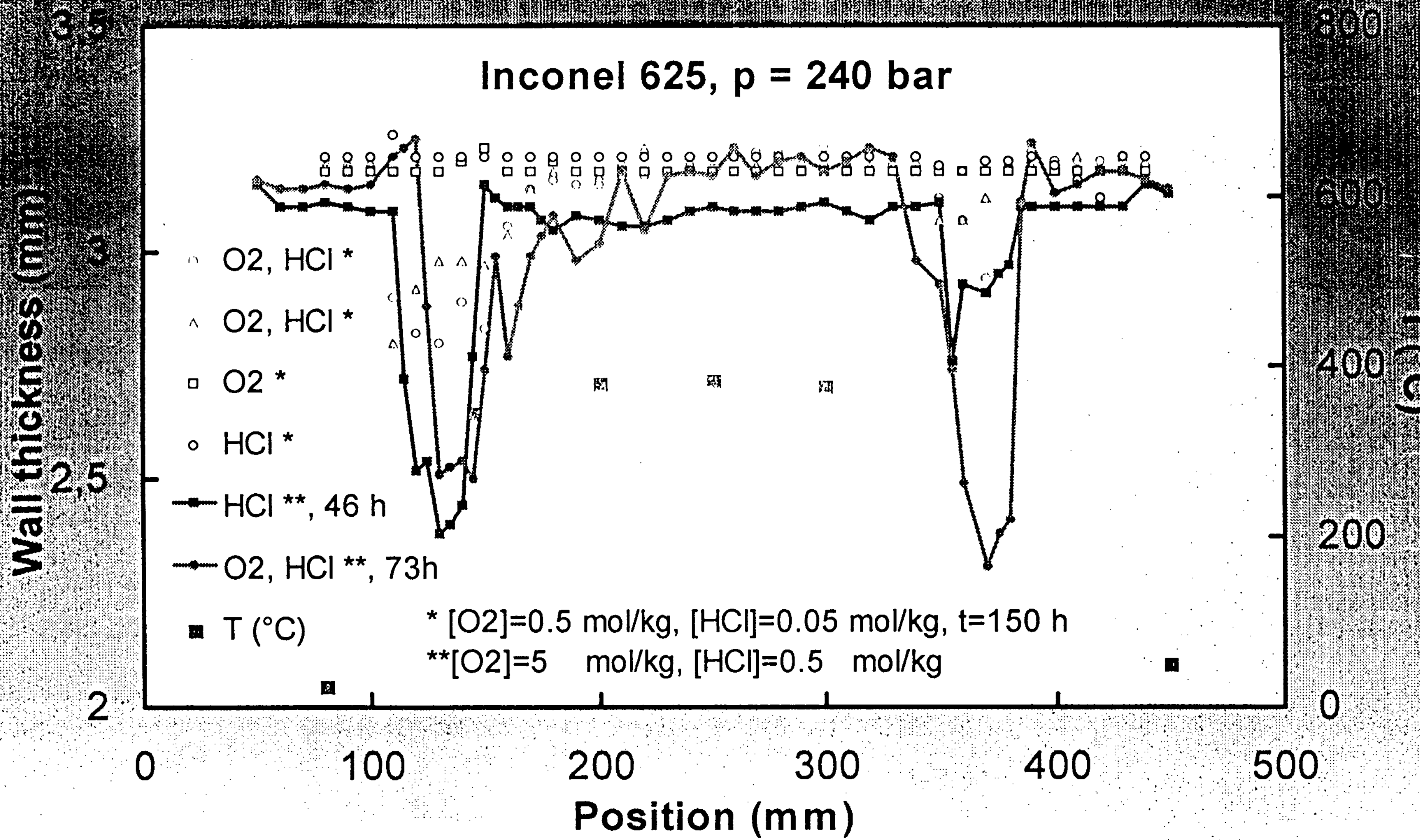
OPERATING DIAGRAMM OF BENCH SCALE
(ACRYLIC ACID, aq. Effluent)

Summarised Chemical Findings in Near- (NCW) and Supercritical Water (SCW)

- Aromatic compounds without heteroatoms (e.g. tert.-Butylbenzene), show no or only very slow ring cleavage in NCW and SCW: *free radical pyrolysis*
  (A. Kruse and K.H. Ebert, Ber. Bunsenges. Phys. Chem. *100*, 80-83, 1996)
- Oxygen-bridged networks of aromatic compounds (e.g. lignin) split favourably to low aromatic compounds (phenols) in NCW and SCW: *acid-base catalysed hydrolysis*
  (A. Kruse et al. unpublished)
- Carbohydrates gasify already in NCW fast and in the presence of a catalyst (e.g. K-, Na-salt) complete (without soot): *acid-base catalysed hydrolysis + catalysed pyrolysis*
  (D. C. Elliott et al.; Ind. Eng. Chem. Res. *32*, 1535-1541; 1993 | M. J. Antal, Jr. et al.; Energy & Fuels *7*; 574-577; 1993 | A. Kruse et al. unpublished)
- **SCWO: Oxidation with oxygen excess of organic material (including heteroatoms) is very fast and complete (250 bar, $\leq$ 600°C):** *free radical oxidation*
- **Alcohols and toluene are oxidised in the reaction medium CO_2 as fast and complete as in SCW under the same conditions; pressure is the decisive parameter:** *free radical oxidation*
- **The shift reaction ($CO + H_2O \rightarrow CO_2 + H_2$) seems to be fast in SCW.**

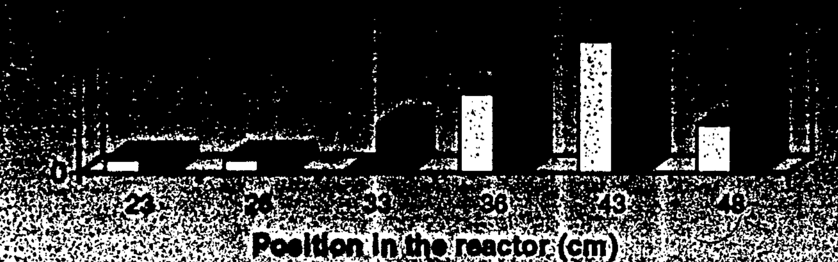
Materials

- Stainless steels 316, 254, 654
- Ni-base alloys
- Ti, Ta, Au, Pt, Cr, Ni
- [illegible]


Inconel 625, p = 240 bar
Wall thickness (mm)
3,5
3
2,5
2
T (°C)
800
600
400
200
0
Position (mm)
0
100
200
300
400
500
O2, HCl *
O2, HCl *
O2 *
HCl *
HCl **, 46 h
O2, HCl **, 73h
T (°C)
* [O2]=0.5 mol/kg, [HCl]=0.05 mol/kg, t=150 h
**[O2]=5 mol/kg, [HCl]=0.5 mol/kg

First data on the corrosion of Ti (Gr. 2) under SCWO conditions

$[O_2]$=0.5 mol/kg; [HCl]=0.05 mol/kg, p=250 bar

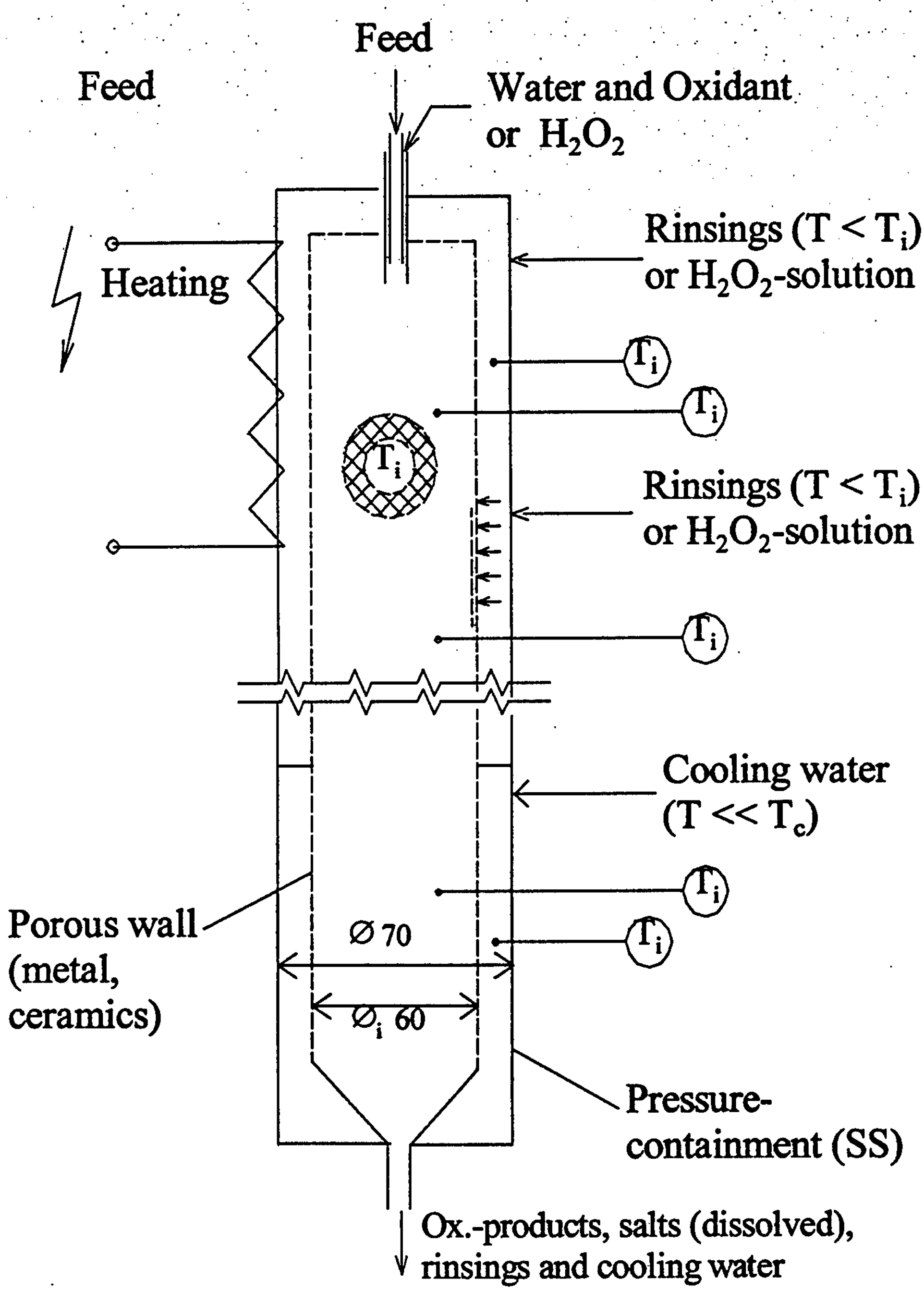


Hong, Hazlebeck

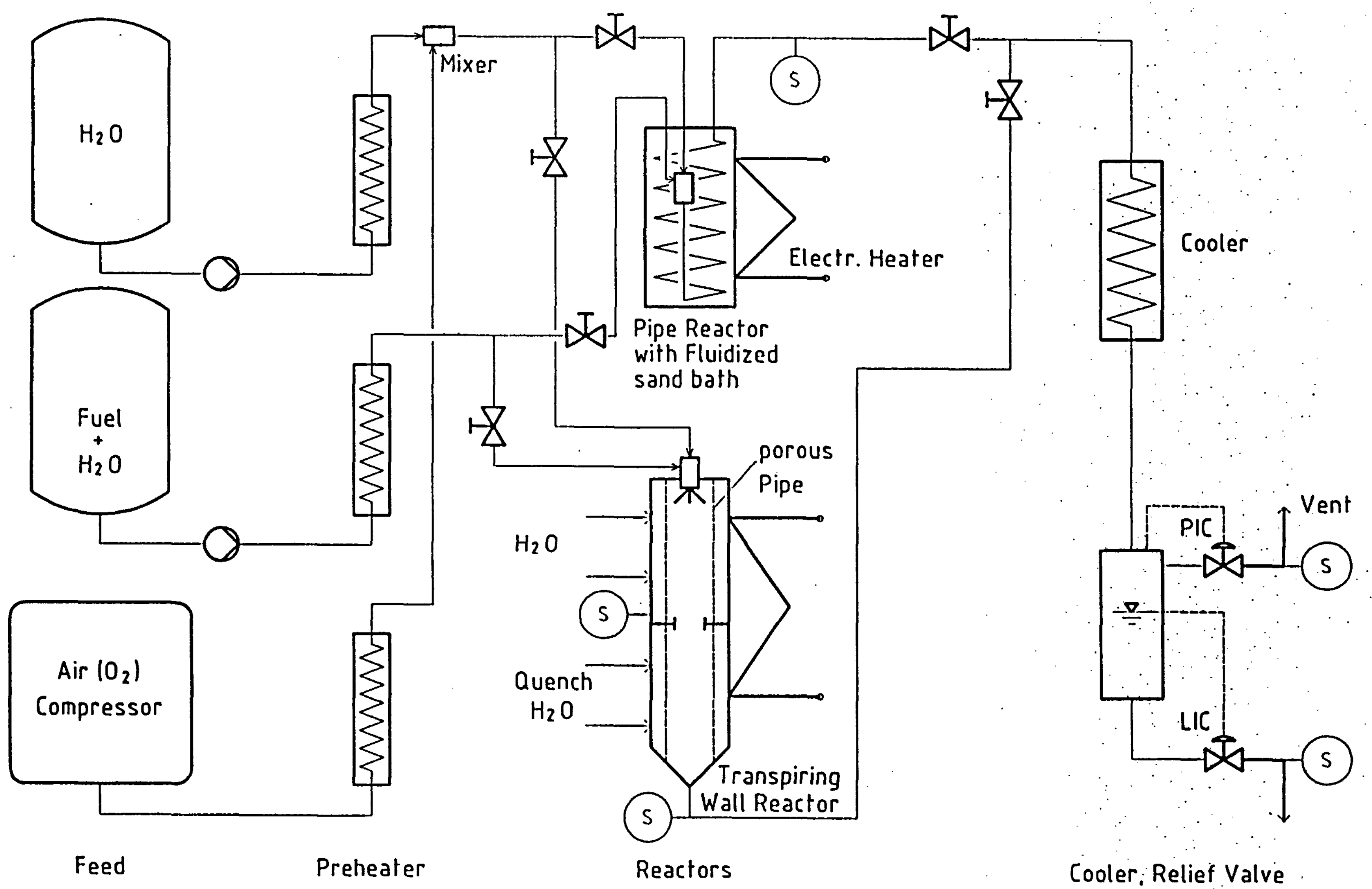
Solution	Corrosion rates
Trimsol (HCl, H_2SO_4); Ti Gr.: 2, 9, 12, 18, β-C	T < 380 °C no corrosion T ≈ 610 °C < 200 mil/a
warfare agent (Cl and S)	T = 350 - 550 °C 10 - 200 mil/a

Summarised Findings: CORROSION

- Small amounts of Cl, S, P (< 1000 ppm) in oxygen containing water are unproblematic regarding corrosion.
- In the main reaction zone (T > 400 C) is the corrosion low even at higher HCl concentrations (20000 ppm).
- Corrosion problems (Ni-alloys, HCl) become severe in the preheating and cooling section (near critical temperature).
- Al_2O_3, ZrO_2 and Ti are sufficient corrosion resistant and can be used as liner to protect the preheating and cooling section.



SCHEME OF TRANSPIRING WALL REACTOR


H2O
Fuel + H2O
Air (O2) Compressor
Mixer
Electr. Heater
Pipe Reactor with Fluidized sand bath
Cooler
porous Pipe
H2O
Quench H2O
Transpiring Wall Reactor
PIC
Vent
LIC
S
Feed
Preheater
Reactors
Cooler, Relief Valve

SC- PILOT

COSTS

Depend sensitively on:

- **Type of waste treated,**
- **suitable reactor concept and plant design and of course**
- **plant size.**

SUMMARY

- Also with air as oxidant instead of pure oxygen the wanted fast and complete destruction can be achieved.
- Tubular and vessel reactors (Ni-alloy, SS) are suitable for treatment of unproblematic wastes (organics without or with only small amounts of Cl, S, P, sewage e.g.).
- For high concentrations of corrosives lining with stable materials (Ti, Ta) solve the problems.
- To avoid clogging of the reactor caused by high salt concentrations a vessel (MODAR concept for example) or a transpiring wall reactor should overcome the problems.

<u>Session</u> 4 - Supercritical Water Oxidation Technologies

Use of Supercritical Water Oxidation for the On-Board Treatment of Naval Excess Hazardous Materials

by Dan D. Jensen,
General Atomics, USA

USE OF SUPERCRITICAL WATER OXIDATION FOR THE ON-BOARD TREATMENT OF NAVAL EXCESS HAZARDOUS MATERIALS

PRESENTED AT THE

US-EUROPEAN WORKSHOP ON
THERMAL WASTE TREATMENT FOR NAVAL VESSELS

SPONSORED BY THE
UNITED STATES NAVY
OFFICE OF NAVAL RESEARCH
EUROPEAN OFFICE
29-31 OCTOBER 1997
BRUSSELS, BELGIUM

WORK FUNDED UNDER
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10-22-97

GENERAL ATOMICS

"USE OF SUPERCRITICAL WATER OXIDATION FOR THE ON-BOARD TREATMENT OF NAVAL EXCESS HAZARDOUS MATERIALS" US-EUROPEAN WORKSHOP ON THERMAL WASTE TREATMENT FOR NAVAL VESSELS

Page No.	Text
Cover	**USE OF SUPERCRITICAL WATER OXIDATION FOR THE ON-BOARD TREATMENT OF NAVAL EXCESS HAZARDOUS MATERIALS** This briefing presents an overview of the use of supercritical water oxidation (SCWO) for the treatment of naval excess hazardous materials (EHMs). General Atomics (referred herein henceforth as GA) has been performing SCWO research and development for DARPA/ONR since 1992 under three separate contracts.
2	**PRESENTATION TOPICS** Three major topics are described • An overview of SCWO at General Atomics • A brief review of SCWO and its advantages • A more detailed discussion of the DARPA/ONR SCWO system being developed for the treatment of shipboard EHMs.
3	**GENERAL ATOMICS** GA is one of the leading advanced technology companies in the U.S. with over 40 years of experience in science-oriented research and development, as well as engineering development. We are located in San Diego, California and are a privately-held company. Our development and demonstration programs span a broad range of activities, including treatment of hazardous wastes, demilitarization of weapons, nuclear fission and fusion, manufacture of unmanned air vehicles, and many others.

"USE OF SUPERCRITICAL WATER OXIDATION FOR THE ON-BOARD TREATMENT OF NAVAL EXCESS HAZARDOUS MATERIALS"
US-EUROPEAN WORKSHOP ON THERMAL WASTE TREATMENT FOR NAVAL VESSELS

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4	**MAJOR MILESTONES IN SCWO DEVELOPMENT AT GA** • GA became involved with SCWO in 1992 when awarded a contract by DARPA/ONR to develop a pilot plant to the demonstrate disposal of (1) GB, VX, and mustard chemical warfare agents, (2) energetics, and (3) other Department of Defense (DoD) wastes. • Later in 1992, the DoD Joint Ordinance Commanders Group/U. S. Air Force (Armstrong Lab) funded a program directed at the removal and disposal of solid rocket propellant from large rocket motors, including SCWO treatment of hydrolyzed propellant • In 1995, GA was awarded a second DARPA/ONR contract aimed at shipboard treatment of U. S. Navy EHMs. The results of this effort are the focus of this presentation. GA, via its acquisition of the assets of Modar, Inc., continued a related DARPA/ONR project to develop a system to remove particulates and heavy metals from SCWO effluent.
5	**MAJOR MILESTONES IN SCWO DEVELOPMENT AT GA (Cont'd)** • In 1995, GA also established a Cooperative Research and Development Agreement (CRADA) with Los Alamos National Laboratory for research on corrosion of materials in SCWO environments. • In late 1996, GA acquired the assets of Modar, Inc. Modar had been leader in the development of SCWO technology since the early 1980's and significantly expanded GA's research, technology and patent base. • A variety of activities have been undertaken in 1997: - Extended testing of biosolids and industrial wastes (customer-funded) - Gasification of biomass (sewage sludge) for the production of hydrogen, supported by the U. S. Department of Energy - Extended tests of hydrolyzed VX chemical agent for the U. S. Army for proof-of-process testing for a full-scale bulk agent disposal plant at Newport, Indiana - Delivery of a small SCWO test system to the U. S. Air Force - A follow-on program with the U. S. Air Force to further develop SCWO treatment of solid rocket propellants. • Together, the programs at GA represent well over \$20M in SCWO research, development and demonstration, not including the prior work carried out by Modar prior to its acquisition by GA.

"USE OF SUPERCRITICAL WATER OXIDATION FOR THE ON-BOARD TREATMENT OF NAVAL EXCESS HAZARDOUS MATERIALS"
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6	**GENERAL ATOMICS SCWO PILOT PLANTS** GA has designed and built three large pilot plants • The DARPA/ONR pilot plant was completed in early 1995. It is capable of processing up to 2 L/min of aqueous feed and has seen nearly continuous use since its startup for treatment of a broad range of feeds. • The Air Force Pilot Plant, shown here at its current location in Utah, is used to process solid rocket propellants and other energetics. It has a throughput capability of 2L/min • The Modar pilot plant was operated for many years at its Natick, Massachusetts site before being transferred to GA's facilities in San Diego. Its throughput is comparable to that of the DARPA/ONR and Air Force pilot plants.
7	**SCWO PROCESS**
8	**SCWO IS A SAFE, SIMPLE PROCESS** SCWO involves the mixing of an organic feed with water and an oxidant, subjecting the aqueous mixture to supercritical conditions, cooling the effluent, reducing the pressure, and separating the gases from the liquids and solids. A large variety of system designs have been developed to carry out this process.
9	**SCWO OXIDIZES ORGANIC WASTES** • SCWO is usually performed at temperatures and pressures above the critical point of water, 374°C and 22.1 MPa. Typical operating temperatures are 600 to 650°C, with pressures ranging up to 60 MPa and more. Treatment can also be carried out at supercritical temperature and subcritical pressures, resulting in a reduced fluid density but less demanding materials of construction issues. • Oxidants can be air, O_2, H_2O_2, or HNO_3. Air and oxygen are used most often. • SCWO results in oxidation of organics to CO_2, H_2O, and inorganic acids or salts. A variety of design considerations are involved in determining the best means of handling acids, salts, and potential corrosion (e.g., feed additives, corrosion-resistant materials and liners, salt removal mechanisms).

"USE OF SUPERCRITICAL WATER OXIDATION FOR THE ON-BOARD TREATMENT OF NAVAL EXCESS HAZARDOUS MATERIALS"
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10	**ADVANTAGE OF SCWO** SCWO has a number of advantages versus alternates disposal methods • It provides excellent kinetics and destruction efficiency due to the high temperature and fluid derisity present under SCWO conditions • It releases no airborne particulates and only very low levels of NO_x. SO_x, and residual organics. As a result, no air pollution equipment is required to treat the gaseous effluent. • It provides excellent process stability and control, with system operating conditions easily monitored at all times during operation. • It requires only simple, widely demonstrated safety measures, with process upsets accommodated in a straight-forward manner. • It offers the capability of complete containment of solid, liquid and gaseous effluents, allowing monitoring for hazardous constituents prior to release. • It provides a highly compact design, as will be shown in the following sections of this presentation.
11	**DARPA/ONR SCWO SYSTEMS FOR NAVAL SHIPBOARD EXCESS HAZARDOUS MATERIALS**
12	**DARPA/ONR NAVY SCWO PROGRAM** This chart highlights the key features of the DARPA/ONR Navy SCWO program. As noted earlier, the project was begun in 1995, with systems engineering, research and design completed during 1996. Work during 1997 has been focused on fabrication of the compete skid and start of testing at GA.

"USE OF SUPERCRITICAL WATER OXIDATION FOR THE ON-BOARD TREATMENT OF NAVAL EXCESS HAZARDOUS MATERIALS" US-EUROPEAN WORKSHOP ON THERMAL WASTE TREATMENT FOR NAVAL VESSELS

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13	**PROGRAM OBJECTIVES CHALLENGING** The objectives of the project imposed a variety of new challenges to SCWO technology • Process up to 45 kg/hr (100 lb/hr) or 450 kg/hr (1000 lb/day) of EHM. This represents a ~5X increase over the DARPA/ONR pilot plant throughput. • Produce non-toxic effluent that meets all regulatory limits. The main focus of this requirement is shipboard aqueous discharge, particularly into harbors and MARPOL Special Areas, e.g., the Mediterranean Sea • Provide a compact design compatible with limited shipboard space: 3.0 m long, 2.5 m wide and 2.75 m high. This represents a ~5X reduction in space versus the DARPA/ONR pilot plant • System must have very high reliability with minimal maintenance • Operation must be fully automated, with a simple operator interface
14	**BASELINE FEED COMPOSITIONS REPRESENT WORST-CASE EHMs** A variety of feeds were defined that bound the most challenging properties of EHMs. 1. Motor oil (high heat content, zinc) 2. Contaminated hydraulic fluid (high heat content with maximum phosphorus) 3. MoS_2 lube oil/kerosene (maximum sulfur) 4. PCTFE/kerosene (maximum fluorine) 5. TCE/kerosene (maximum chloride) 6. Paint (maximum solids) 7. Photographic fluids (maximum salts) 8. Glycol (maximum antioxidant) While not EHMs, gray water and black water were also defined a potential feeds to the system
15	**BASELINE FEED COMPOSITIONS REPRESENT WORST-CASE KITTY HAWK EHMs** The pie chart shows the weight percent of each type of EHM that typically accumulates onboard the aircraft carrier USS Kitty Hawk. Kerosene, hydraulic fluid and waste oil represent over 50% of the feeds, with paint wastes making up another 14%.

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16	**EXCELLENT BASELINE EHM FEED DESTRUCTION DEMONSTRATED IN PILOT PLANT TESTS** A series of tests were performed in the DARPA/ONR pilot plant for each of the EHM feeds. Each feed is shown before and after its treatment in the pilot plant. In each case, a clear, odor-free effluent was produced, with metal oxides being formed from MoS_2 and paint feeds. Total organic carbon (TOC) destruction was greater than 99% in all cases, and generally greater than 99.99%.
17	**PROCESS FLOW DIAGRAM DEVELOPED FROM DARPA/ONR PILOT PLANT TESTING** This figure shows the major process components for the shipboard SCWO unit. • EHM and auxiliary fuel are drawn from drums, mixed with fresh water and fed into an emulsifier and high pressure pump. • Ambient air is compressed by an on-skid compressor • The pressurized mixture of feed, water, and air are then introduced into the reactor for thermal treatment. • Fresh water at high pressure is introduced into the discharge end of the reactor to partially cool the reactor effluent • Solids are removed from the effluent stream by a hot, high pressure filter before the system pressure is let down and further cooled with seawater from the ship's fire main. • The cooled, neutralized liquid effluent is discharged overboard, with gases being released to the atmosphere.
18	**COMPLETED SKID HAS COMPACT DESIGN** Two views of the skid are shown. • The Reactor End view shows an auxiliary fuel barrel in front of the reactor on the left-hand side of the skid, with the solids filter shown on the right. An EHM feed barrel is located adjacent to the auxiliary fuel barrel during operation. Solids from the solids filter drop into a container beneath the filter (not shown) that is removed and emptied at the end of a shift. • The Compressor End view shows the air compressor and skid electrical and control panels. The compressor occupies 45% of the allowable space on the skid and is a modified version of commercially available units.

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19	**MAJOR ACCOMPLISHMENTS LEADING TO SYSTEM DESIGN/FABRICATION** • A number of major technical challenges were addressed prior to final design and fabrication of the system - Corrosion from EHMs: corrosion-resistant materials were defined for all baseline feeds - Pumping EHMs: pumping system for paint solids - the most difficult EHM to feed - and other feeds was developed - Cold feed injection of EHMs: this step eliminates heating of the feeds before introduction into the reactor, simplifying the overall process - Salts/solids holdup and removal from reactor, and transport through system: reliable means were demonstrated in the DARPA/ONR pilot plant that ensure long-term operation of the system. - Salts/solids separation/collection (wet or dry): the system includes a hot filter to remove solids from the supercritical fluid. An alternate wet collection and removal system is being developed for a related DARPA/ONR project. - Effluent quench: partially cooling of the reactor effluent was demonstrated in pilot plant tests. • The test and design effort also drew heavily from prior DARPA/ONR and Air Force programs that had a strong research and development focus. • Completion of the Navy system test program and fabricated skid provides a good foundation for verification testing at GA being planned by DARPA/ONR in cooperation with the U. S. Navy.
20	**TWO METHODS BEING DEVELOPED TO REMOVE SOLIDS AND SOLUBLE HEAVY METALS.** • The Dry Filter photo shows a close-up view of the filter installed in the Navy skid. This operates at supercritical conditions and provides automatic discharge of dry solids using compact, simple equipment. • The Wet Filter photo shows a high-shear, rotating filter that can be used to remove solids from a cooled (~50°C) effluent stream. This filter was developed for an alternate SCWO system that does not incorporate a hot filter. A downstream ion exchange column capable of removing dissolved heavy metals from seawater is an integral part of the wet filter system.

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21	**WHAT ARE THE SHIP INTERFACE/SYSTEM ISSUES?** Five areas were identified as key interface issues: • Environmental compliance • Shipboard design standards • System size • System weight • Utility requirements
22	**SCWO UNIT DESIGNED TO COMPLY WITH ALL ENVIRONMENTAL REGULATIONS** • Airborne emissions meet or exceed prevailing standards. The extremely low emissions of airborne hazardous species provides an inherent advantage to SCWO systems by eliminating the need for pollution abatement systems. • The hot filter captures solids and all heavy metals (soluble or insoluble in subcritical water), eliminating the need for downstream treatment of the effluent (i.e., a wet filter and ion exchange column are not needed). • TOC destruction of >99.99% is anticipated for all EHMs, with effluent TOC concentrations <1 ppm. • Seawater quench increases the pH of the effluent to >5, ensuring compliance with prevailing discharge limits
23	**SHIPBOARD SCWO UNIT DESIGNED TO THE FOLLOWING STANDARDS** The following items were addressed in the design of the SCWO system: • Noise — MIL-STD-740 — Limited to Grade E level • Shock — MIL-STD-901 — Designed for Grade B shock • Vibration — MIL-STD-167 — Isolation mounts used for major equipment • Ship Motion — DoD-STD-1399 — Bracing for 20° roll, 1.7 g • EMI — MIL-STD-461 — Comparable to other ship sources • IR Signature — - — Hot components insulated; effluent cooled to <52°C

"USE OF SUPERCRITICAL WATER OXIDATION FOR THE ON-BOARD TREATMENT OF NAVAL EXCESS HAZARDOUS MATERIALS" US-EUROPEAN WORKSHOP ON THERMAL WASTE TREATMENT FOR NAVAL VESSELS

Page No.	Text
24	**SIZE, WEIGHT AND UTILITY REQUIREMENTS COMPATIBLE WITH LARGE NAVAL VESSELS** • Size is compatible with existing space on-board an aircraft carrier • Weight is approximately 12,000 kg, which can be moved by existing elevators and cranes on board an aircraft carrier. The largest component, the compressor, can be handled with a large forklift. • Utilities requirements represent only a small fraction of a ship's capacity - Electrical power: 300 to 400 kW - Seawater: 0.95 m^3/min - Freshwater: 7.6 L/min - Low pressure air: <0.15 m^3/min
25	**WHAT ARE THE OPERATIONAL/MAINTENANCE ISSUES?** • Safety - protect personnel from injury and equipment damage that could potential result from high pressure, high temperature operations or other activities • RAM - ensure reliable system operation and maintainability without the needed for one-of-a-kind specialist training and complex maintenance procedures • Operator interface - minimize required operator actions to allow "one-button" operation
26	**SAFETY STRESSED IN GA DESIGN** • Skid had been designed to be enclosed, providing protection against pipe and reactor failures. Related design features were included in the DARPA/ONR pilot plant • The reactor has been designed and tested to ASME Boiler and Pressure Vessel Code, Sec. VIII, Div. 1 • The piping has been designed to comply with ANSI Chemical Plant and Petroleum Refinery Piping Code B31.3 • The control system, based on Allen Bradley commercial hardware, provides automatic shutdown in the event of a component failure. Operators are alerted as to cause of shutdown and recommended course of action for repair.

Page No.	Text
27	**RAM STRESSED IN GA DESIGN** • Qualitative reliability data on SCWO components was gathered from major SCWO investigators in U.S. and component vendors. It is difficult to obtain comprehensive quantitative data for a rigorous RAM analysis at this time. • RAM Failure Mode and Effects Analysis (FMEA) was performed per MIL-STD-1629 - Equipment failure modes and causes were identified for each component - The failure effects were estimated - Mitigating provisions were proposed to reduce the severity of the failure - Final severity category was assigned to each failure • The control system has also been programmed to prompt operator when key components (e.g., compressor) require routine maintenance
28	**OPERATOR REQUIREMENTS MINIMIZED** Simple operation was a key driver in the overall skid design • Touch screens are used to start and stop the process • Liquid crystal display is used for alarms and diagnostics • Operator actions are limited to (1) loading feed drums and removing collected solids, and (2) performing off-shift routine maintenance. • The PLC-based control system provides for automated control of startup, operation, and shutdown. System is design to automatically recognize and adjust for aqueous or nonaqueous feeds.

"USE OF SUPERCRITICAL WATER OXIDATION FOR THE ON-BOARD TREATMENT OF NAVAL EXCESS HAZARDOUS MATERIALS"
US-EUROPEAN WORKSHOP ON THERMAL WASTE TREATMENT FOR NAVAL VESSELS

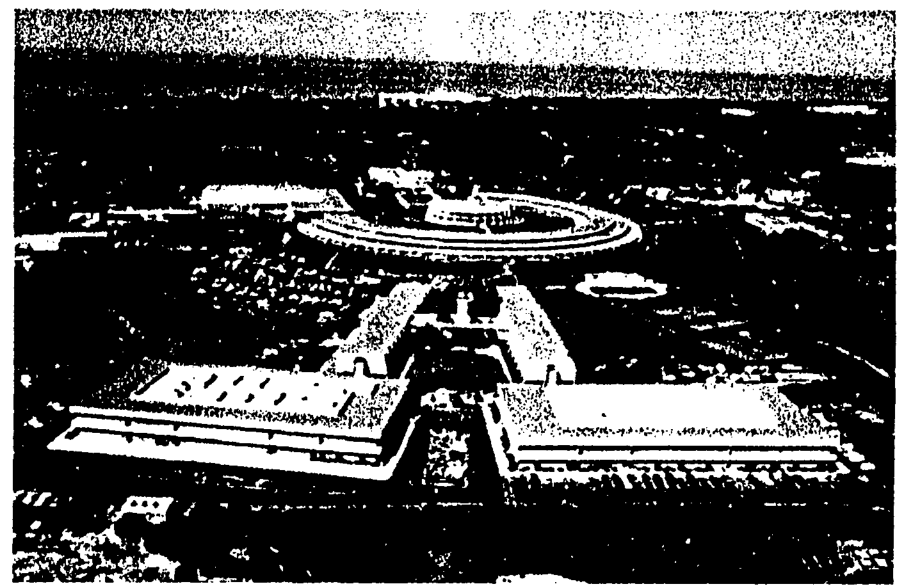
Page No.	Text
29	**PROTOTYPE UNIT COULD ALSO ACCOMMODATE WIDE RANGE OF SHIPBOARD WASTES** While the scope of the DARPA/ONR project is focused at pumpable liquid EHMs, the SCWO system can handle a wide variety of liquid and solid feeds • Dirty laundry water can be fed directly to the SCWO system without further treatment • Solid materials can be fed to a solid processing unit for size reduction and blending with water and fed to the system • Gray/black water can be concentrated (e.g., using the wet filter skid under development by DARPA/ONR) and fed to the system. Similar biosolids feeding has been demonstrated in the DARPA/ONR pilot plant for extended periods of time.
30	**CONCLUSIONS** • The SCWO demonstration/prototype unit meets U S. Navy design and operating requirements for use aboard an aircraft carrier. Smaller systems can be designed for other naval vessels • Initial testing of the system will be completed in the Spring of 1998. DARPA/ONR are now planning a series of tests with all EHMs that will extend over hundreds of hours of operation • The system can be used not only with liquid, pumpable EHMs, but also with a wide variety of solid and liquid feeds, as demonstrated in shore-based testing in a variety of pilot plants.

PRESENTATION TOPICS

- OVERVIEW OF SCWO AT GENERAL ATOMICS
- SCWO PROCESS
- DARPA/ONR SCWO SYSTEM FOR NAVAL SHIPBOARD EXCESS HAZARDOUS MATERIALS (EHMs)

GENERAL ATOMICS

LOCATION:	San Diego, California
FOUNDED:	1955 by General Dynamics
STATUS:	Privately held corporation
OWNERS:	Neal and Linden Blue
BUSINESS:	High technology research, design, manufacturing, and production for industry and Government in the U.S. and overseas



2

MAJOR MILESTONES IN SCWO DEVELOPMENT AT GA

1992
- ARPA/ONR program focused on chemical warfare agents, energetics and other DoD wastes
- Joint Ordinance Commanders Group/U.S. Air Force (Armstrong Lab) program directed at solid rocket propellants

1995
- DARPA/ONR program aimed at shipboard treatment of Navy excess hazardous material
- Related DARPA/ONR program directed at heavy metals removal from SCWO effluent

MAJOR MILESTONES IN SCWO DEVELOPMENT AT GA

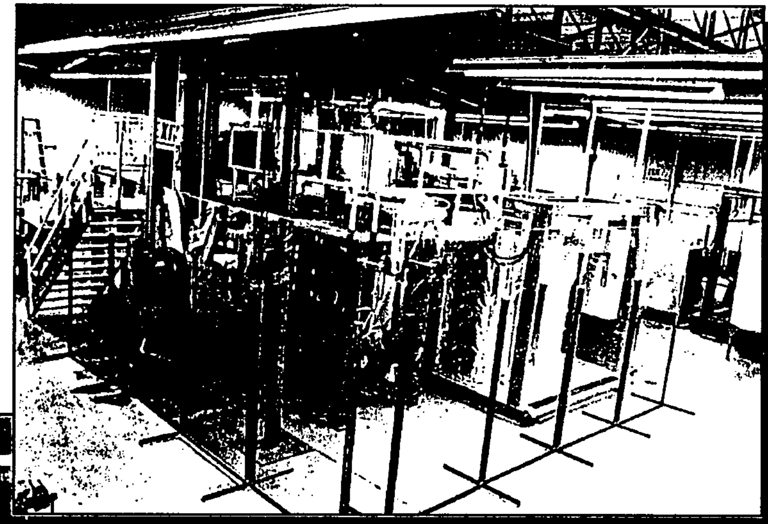
1995
- CRADA with Los Alamos National Lab for SCWO corrosion testing

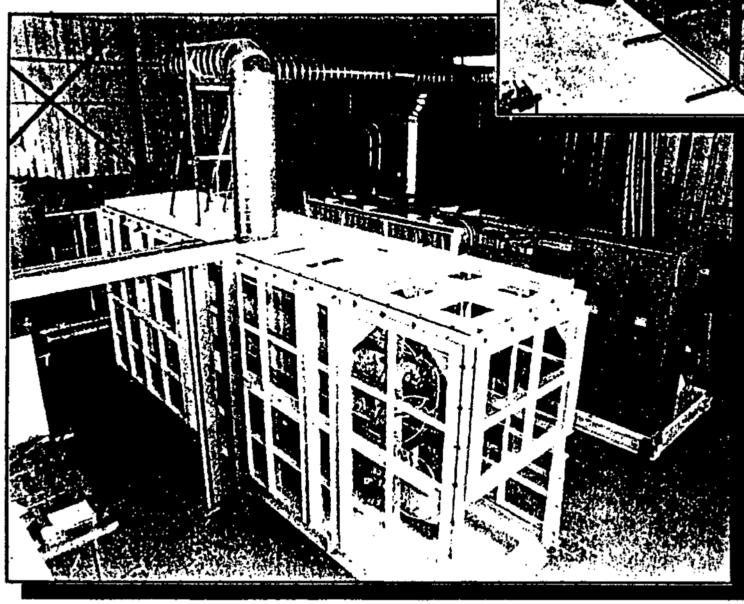
1996
- Acquisition of MODAR, Inc. assets

1997
- Customer-funded treatment of municipal sludge ("biosolids") and industrial wastes
- Gasification of biomass for U.S. DOE
- Extended tests of hydrolyzed VX chemical agent for U.S. Army
- Test SCWO system for Air Force
- Follow-on Air Force program related to solid rocket propellants

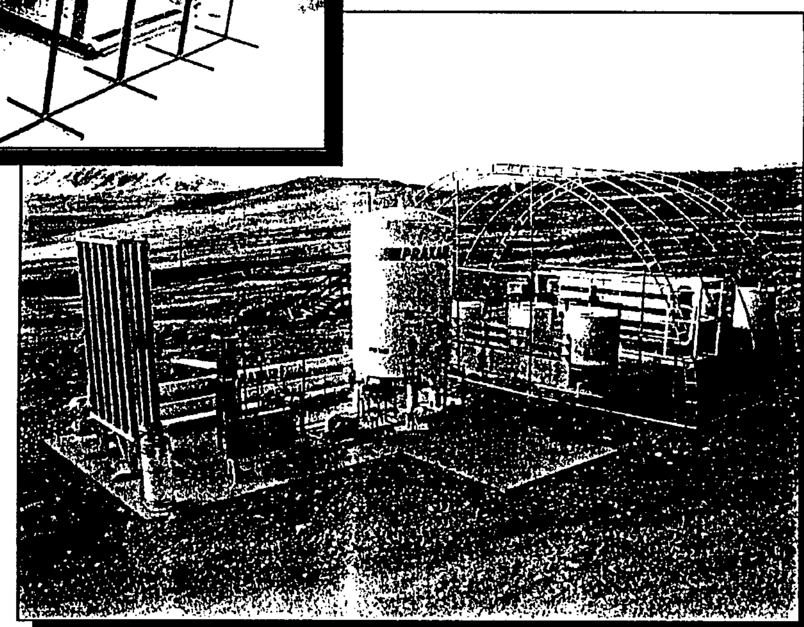
GENERAL ATOMICS SCWO PILOT PLANTS

MODAR Pilot Plant





DARPA/ONR Pilot Plant



Air Force Pilot Plant

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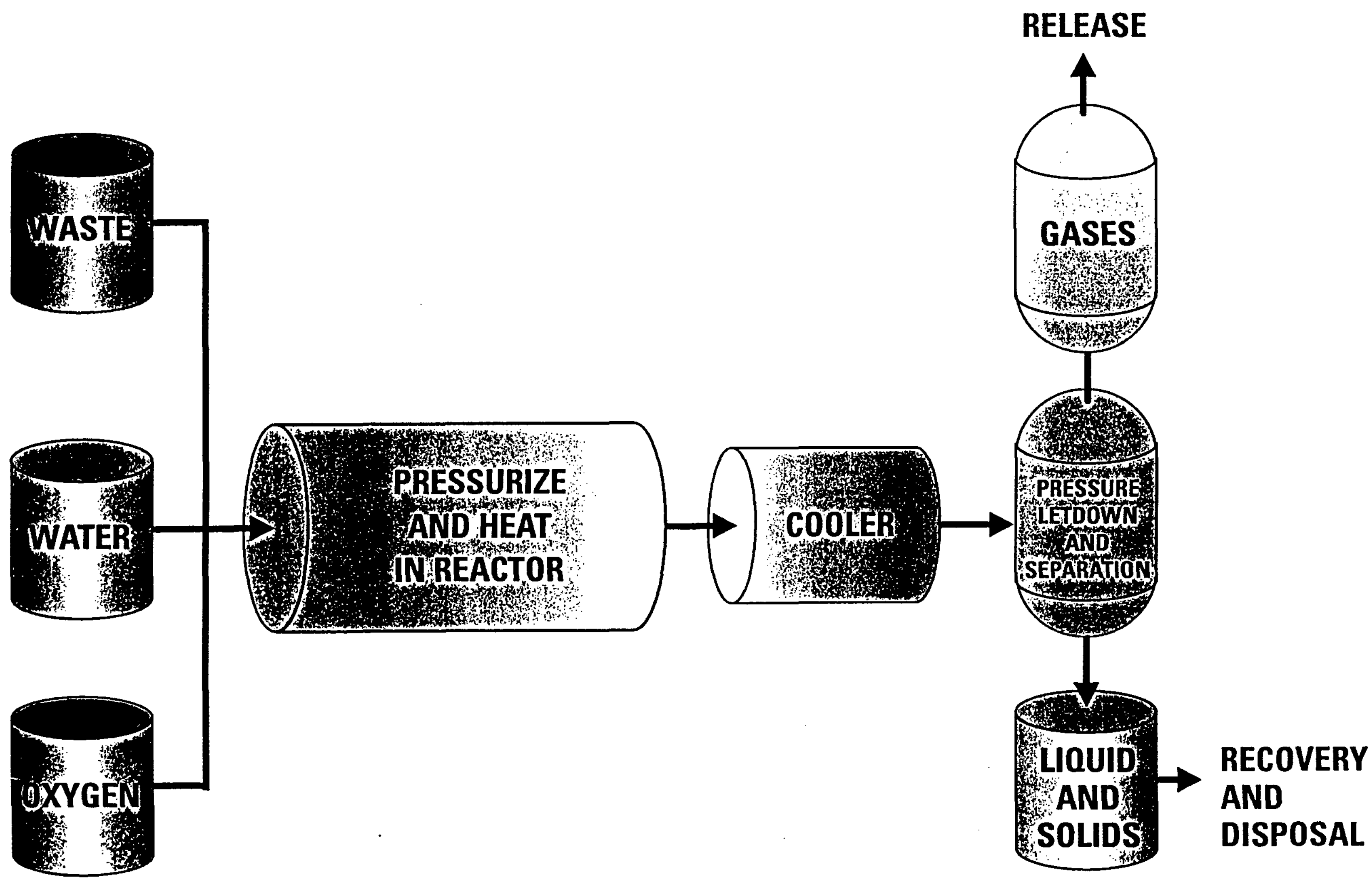
GENERAL ATOMICS

5

SCWO PROCESS

SCWO IS A SAFE, SIMPLE PROCESS



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12-9-96

GENERAL ATOMICS

7

SCWO OXIDIZES ORGANIC WASTES

- Oxidation of a combustible material at temperatures and pressures above the critical point of water, 374°C and 22.1 MPa (3200 psi)
- Oxidant can be air, O_2, H_2O_2, or HNO_3
- Complete oxidation to CO_2, H_2O, and inorganic acids for most organic feeds

8

ADVANTAGE OF SCWO

- Excellent kinetics/destruction efficiency
- No airborne particulates
- Low NO_X, SO_X, and residual organics
- Excellent process stability/control
- Simple safety measures/process upset recovery
- Capability for complete containment of effluents
- Compact equipment

9

DARPA/ONR SCWO SYSTEM FOR NAVAL SHIPBOARD EXCESS HAZARDOUS MATERIALS

10

GENERAL ATOMICS

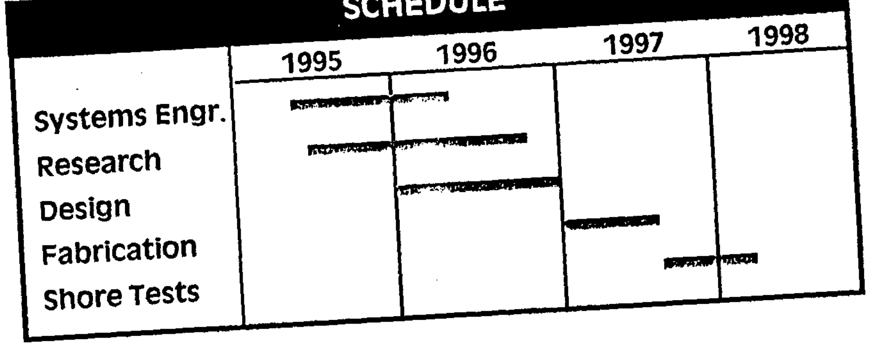
DARPA NAVY SCWO PROGRAM

OBJECTIVES

Design, develop, and demonstrate a full-scale 45 kg/hr SCWO unit for treatment of Navy shipboard excess hazardous materials that:

- Meets International, Federal, State, and Local environmental requirements
- Has dimensions less than 2.5 m x 3 m x 2.75 m
- Is self-contained and simple to operate and maintain
- Is compatible with eventual testing at sea

SCHEDULE



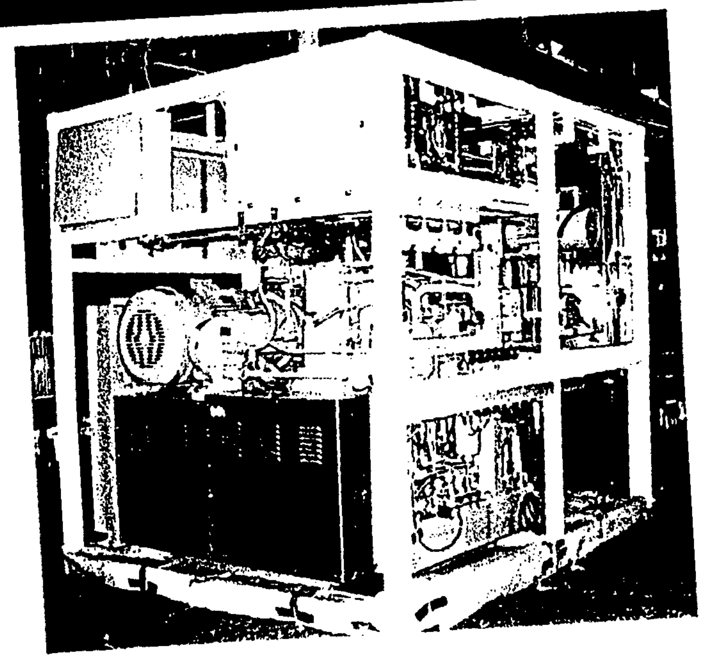
GENERAL ATOMICS TEAM

Eco Waste Technologies

University of Texas at Austin

Support by Los Alamos National Laboratory, H.M. Rosenblatt, and CDI Marine

REFERENCE DESIGN



GENERAL ATOMICS

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PROGRAM OBJECTIVES CHALLENGING

- Process 45 kg/hr (100 lb/hr) of EHM, 450 kg (1000 lb/day)
- Produce nontoxic effluent that meets all regulatory requirements
- Compact unit size: 2.5 m (w) x 3.0 m (l) x 2.75 m (h)
- Very high reliability with minimal maintenance
- Fully automated with a simple operator interface

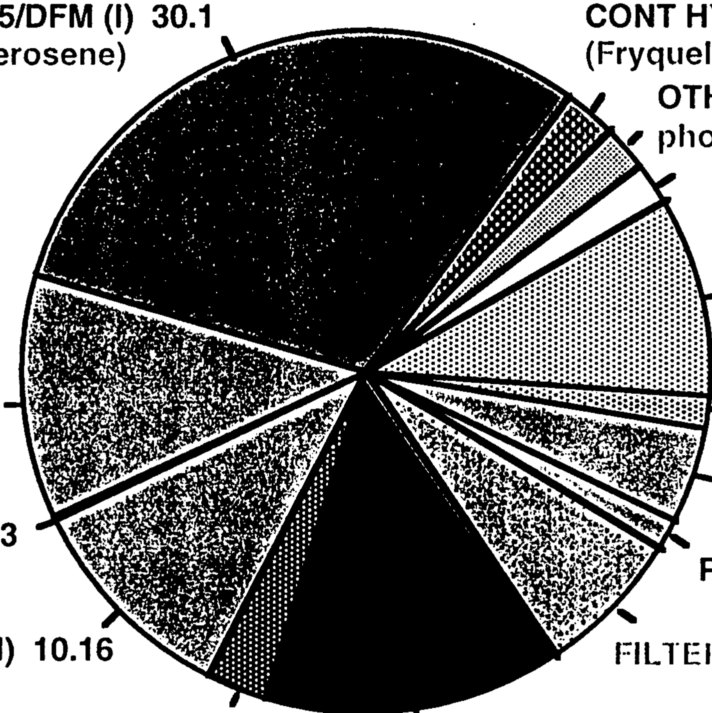
12

BASELINE FEED COMPOSITIONS REPRESENT WORST CASE EHMs

1. Motor oil (high heat content with zinc)
2. Hydraulic fluid (high heat content with maximum phosphorus)
3. MoS_2 lube oil/kerosene (maximum sulfur)
4. PCTFE/kerosene (maximum fluorine)
5. TCE/Kerosene (maximum chlorine)
6. Paint (maximum solids)
7. Photographic fluids (maximum salts)
8. Glycol (maximum antioxidant)

13

BASELINE FEEDS REPRESENT WORST-CASE KITTY HAWK EHMs



l = liquid
s = solid
(Baseline Feeds)
Values in wt %

L-526(3)
6-3-96

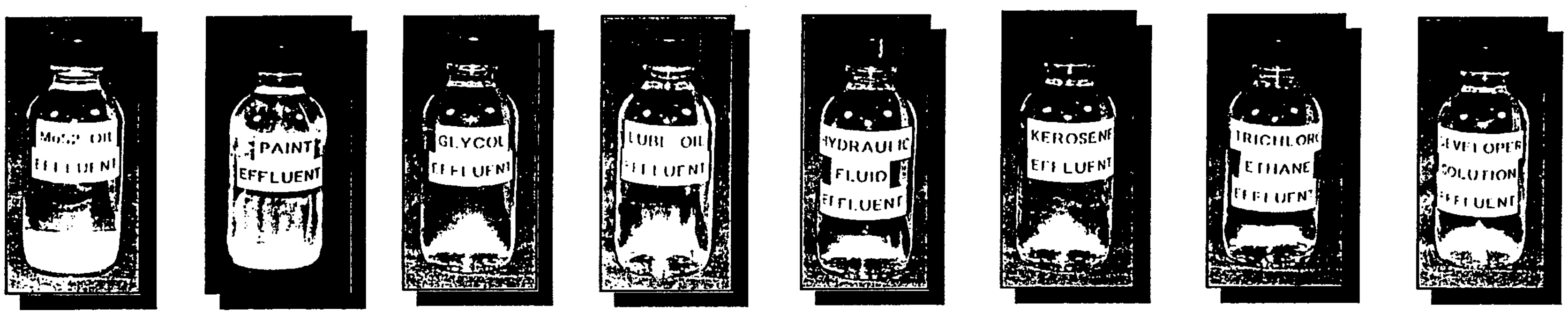
GENERAL ATOMICS

14

EXCELLENT BASELINE EHM FEED DESTRUCTION DEMONSTRATED IN PILOT PLANT TESTS

Before SCWO

After SCWO



>99.998	>99.997	>99.997	>99.990	99.2	>99.998	>99.997	>99.994

% TOC Destruction

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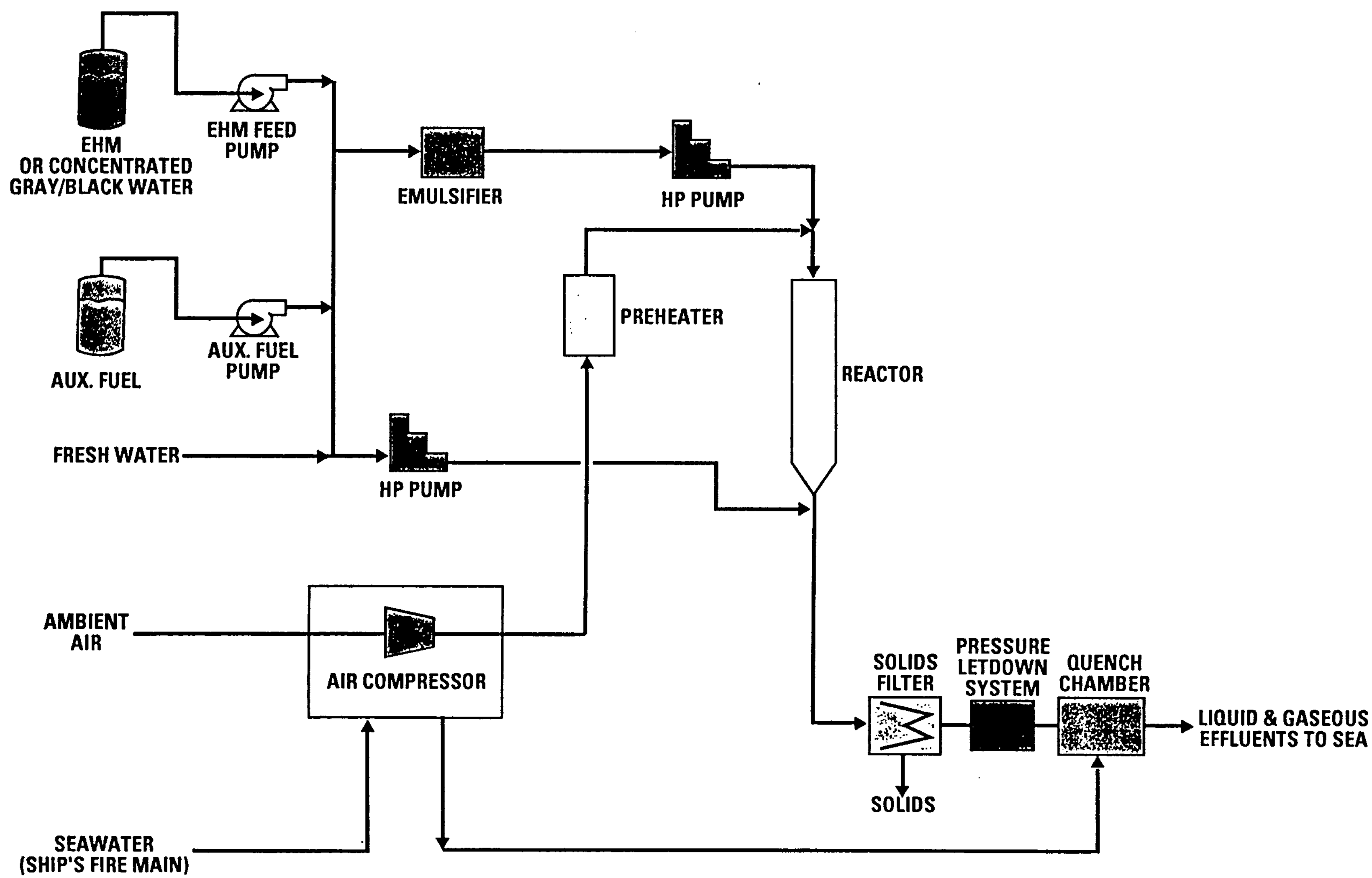
10-22-97

GENERAL ATOMICS

PROCESS FLOW DIAGRAM DEVELOPED FROM DARPA/ONR PILOT PLANT TESTING



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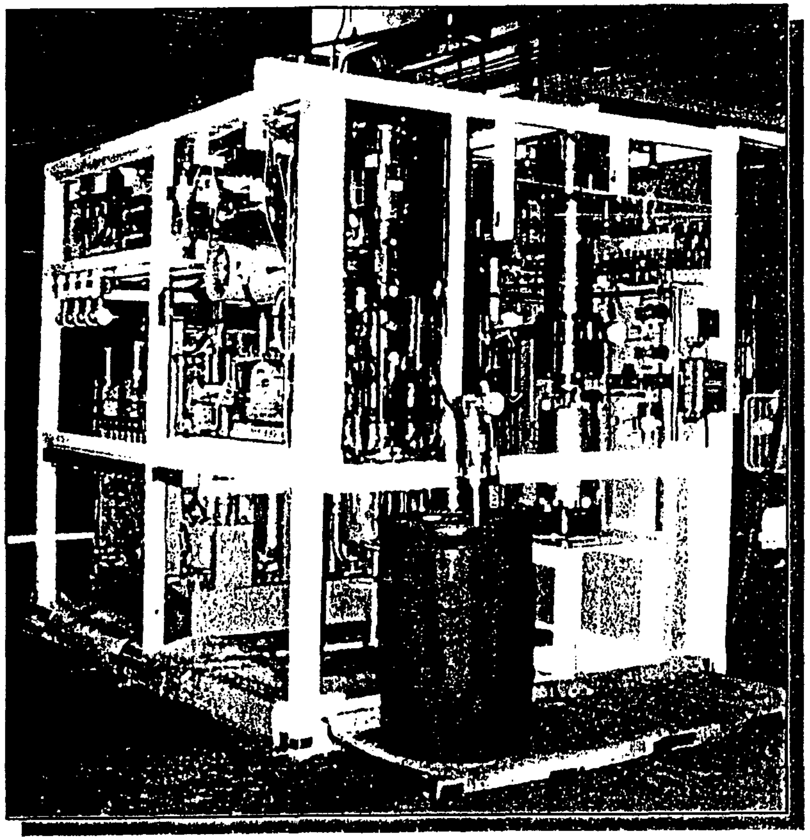
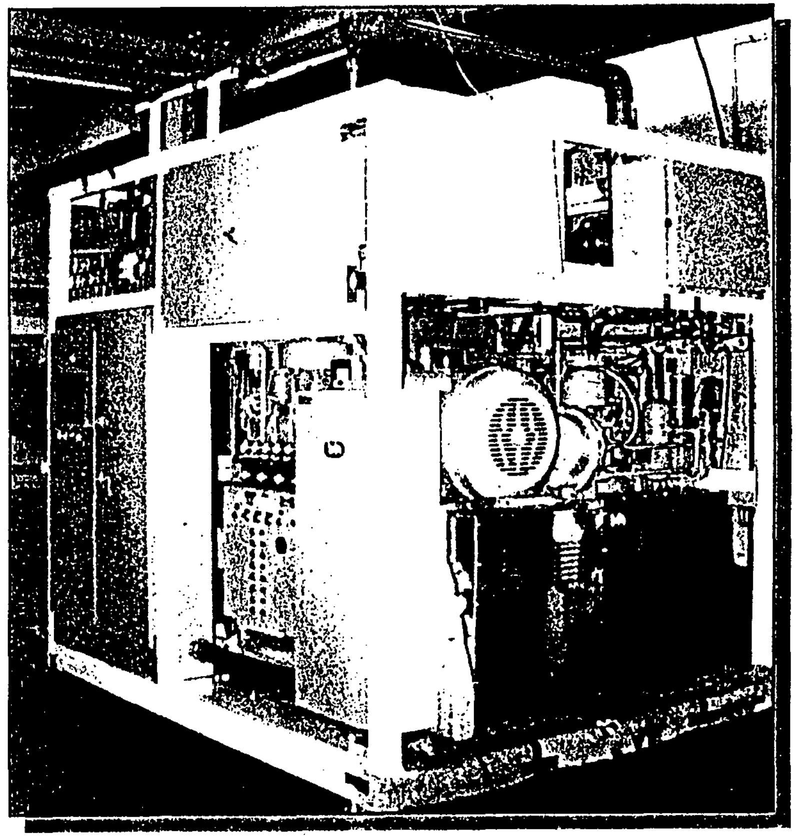
GENERAL ATOMICS

16

COMPLETED SKID HAS COMPACT DESIGN



Reactor End



Compressor End

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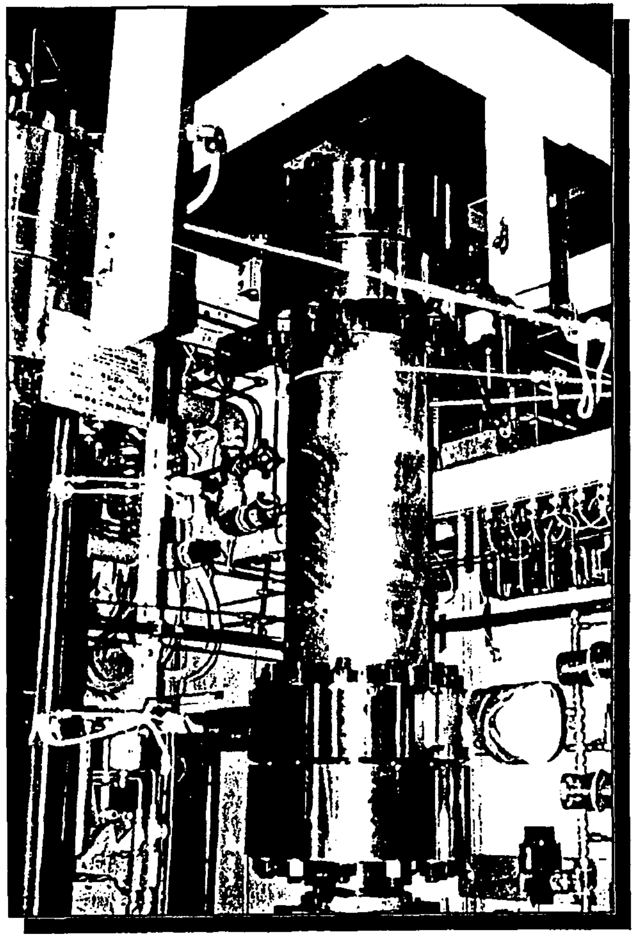
10-22-97

GENERAL ATOMICS

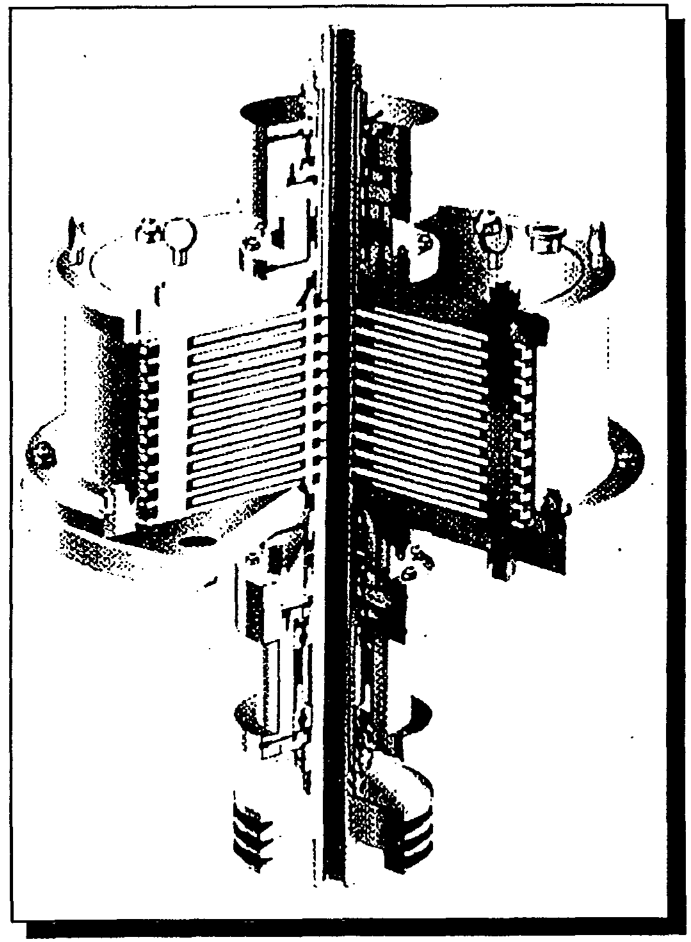
MAJOR ACCOMPLISHMENTS LEADING TO SYSTEM DESIGN/FABRICATION

- All major technical challenges addressed
  - Corrosion from EHMs
  - Pumping EHMs
  - Cold feed injection of EHMs
  - Salts/solids holdup and removal from reactor
  - Salts/solids transport through system
  - Salts/solids separation/collection(wet or dry)
  - Effluent quench
- Built on prior DARPA/ONR and Air Force programs
- Provides good foundation for verification testing

TWO METHODS BEING DEVELOPED TO REMOVE SOLIDS AND SOLUBLE HEAVY METALS



DRY FILTER



WET FILTER

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10-22-97

GENERAL ATOMICS

WHAT ARE THE SHIP INTERFACE/SYSTEM ISSUES?

- Environmental compliance
- Shipboard design standards
- System size
- System weight
- Utility requirements

SCWO UNIT DESIGNED TO COMPLY WITH ALL ENVIRONMENTAL REGULATIONS

- Airborne emissions meet or exceed standards
- Solids filter captures paint solids and all heavy metals (soluble and insoluble)
- Total organic carbon (TOC) destruction of >99.99% expected for all EHMs (effluent TOC <1 ppm)
- Seawater quench increases pH to ≥5

SHIPBOARD SCWO UNIT DESIGNED TO THE FOLLOWING STANDARDS

Item	Standard	Comment
Noise	MIL-STD-740	Enclosure to be insulated to reduce noise to Grade E level. (High noise area where intelligible speech communication is necessary.)
Shock	MIL-STD-901	Designed for Grade B shock. SCWO equipment need not remain operational but must not come adrift or pose hazard to personnel or Grade A equipment.
Vibration	MIL-STD-167	Vibration isolation mounts used with compressor and major pumps
Ships Motion	DOD-STD-1399 Section 301A	Design allows bracing for 20° roll angle = 1.7 g
EMI	MIL-STD-461	SCWO EMI believed comparable to other EMI sources on ship.
IR Signature	—	Hot SCWO components to be insulated and enclosed in an insulated skid. Effluent flow is cooled to <52°C (125°F) prior to discharge below waterline.

SIZE, WEIGHT AND UTILITY REQUIREMENTS COMPATIBLE WITH LARGE NAVAL VESSELS

- Size
  - Skid size is equivalent to 1/4 of an ISO container
- Weight
  - Total weight of HTO unit for CV/CVN is ~12,000 kg (25,000 lb)
  - Can be moved by existing elevators and fork lift
  - Largest component (compressor) can be handled with large fork lift
- Utilities
  - Represent small fraction of ship's capacity

Electrical power:	300-400 kW
Seawater:	0.95 m^3/min (250 GPM)
Freshwater:	7.6 L/min (2 GPM)
Low pressure air:	<0.15 m^3/min (<5 SCFM)

WHAT ARE THE OPERATIONAL/MAINTENANCE ISSUES?

- Safety – protect personnel from injury and equipment from damage
- RAM – ensure reliable system operation and maintainability of equipment
- Operator interface – minimize required operator actions

SAFETY STRESSED IN GA DESIGN

- Enclosure provides protection against pipe and reactor failures
- Reactor designed and tested to ASME Boiler & Pressure Vessel Code, Section VIII, Div. I
- Piping designed to ANSI Chemical Plant and Petroleum Refinery Piping Code, B31.3
- Control system provides automatic shutdown in the event of component failure

25

RAM STRESSED IN GA DESIGN

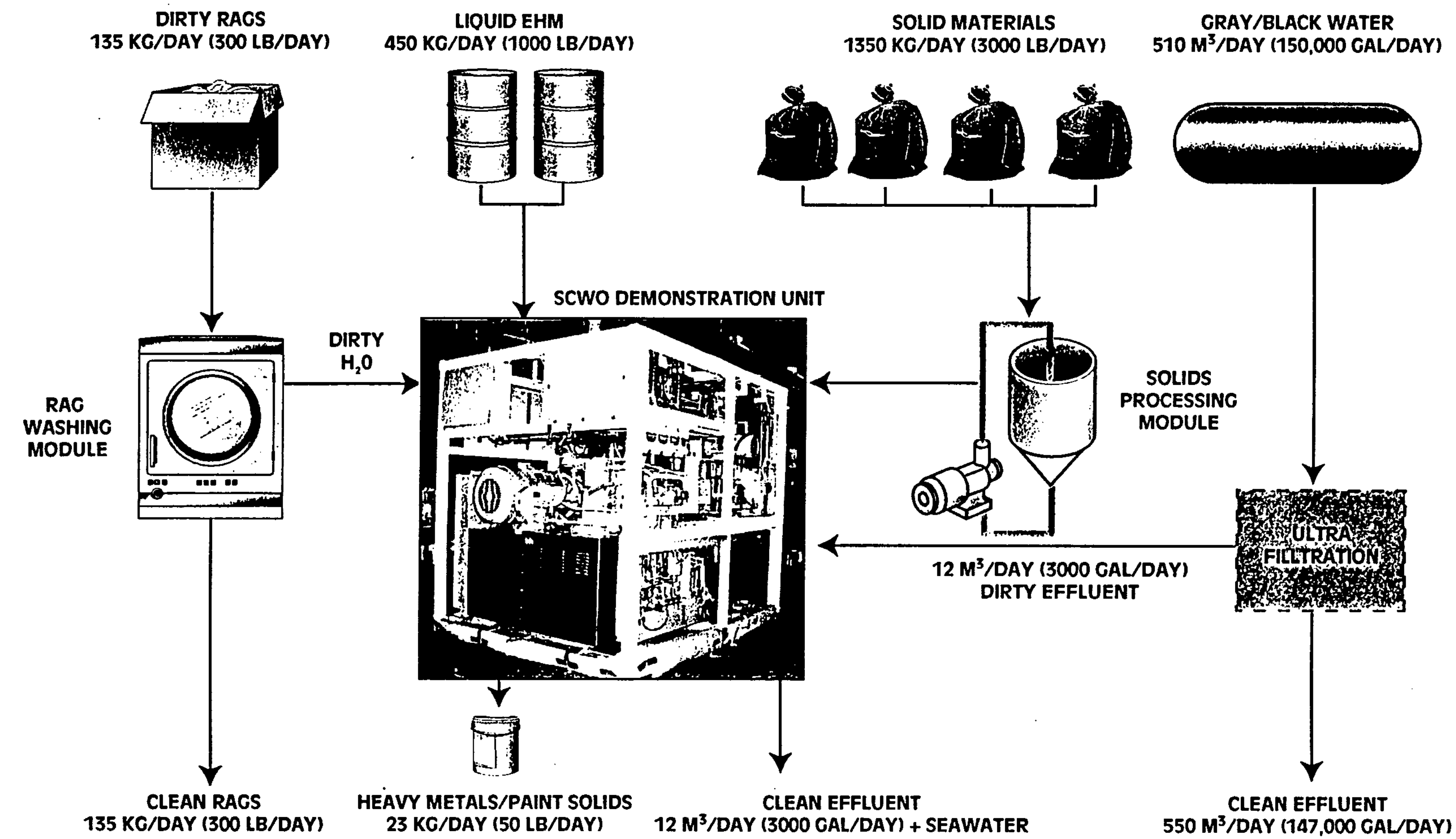
- Qualitative reliability data on SCWO equipment collected from the major SCWO investigators in the U.S.
- RAM Failure Mode and Effects Analysis (FMEA) performed per MIL-STD-1629
  - Equipment failure modes/causes identified
  - Failure effects estimated
  - Mitigating provisions proposed to reduce failure severity
  - Final severity category assigned to each failure
- Control system prompts operator when key components require maintenance

26

OPERATOR REQUIREMENTS MINIMIZED

- Operator interfaces are simple:
  - Touch screen for Start and Stop
  - LCD display for alarms and diagnostics
- Operator actions limited to the following:
  - Load feed drums/remove collected solids
  - Perform routine maintenance (off shift)
- PLC-based control system provides automated control of startup, operation, and shutdown

DEMONSTRATION UNIT CAN ACCOMMODATE WIDE RANGE OF SHIPBOARD WASTES



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GENERAL ATOMICS

CONCLUSIONS

- SCWO demonstration unit meets U.S. Navy design and operation requirements
- Initial testing will be completed by spring 1998
- System can be utilized for broad range of liquid and solid feeds

L-932(7)
10-22-97

GENERAL ATOMICS

Session 4 - Supercritical Water Oxidation Technologies

Hydrothermal Conversion of Wastes

by François Cansell,
University of Bordeaux, France

HYDROTHERMAL CONVERSION OF WASTES

-> Oxidation

-> Reduction

François CANSELL

Research Director (CNRS)

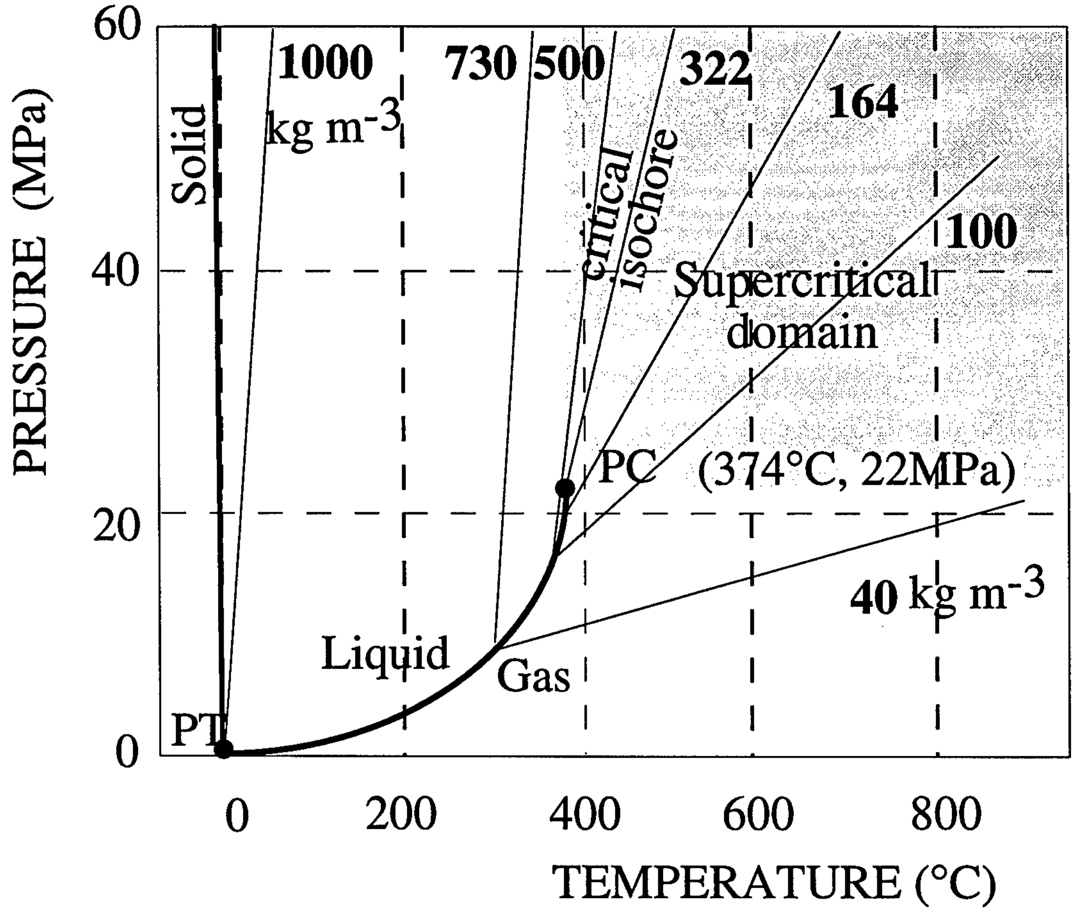
Institut de Chimie de la Matière Condensée de Bordeaux - 33 600 Pessac - France

INTRODUCTION

- Aqueous effluent (1% to 20% weight)
- $C,H,O + xO_2 \text{ ----> } CO_2 + H_2O$
- $C,H,O + xH_2 \text{ ----> } CH_4 + H_2O$
- Current technological environment

  - ☆ Non-toxic end products
  - ☆ Reduce final volume
  - ☆ Pretreatment of effluent
  - ☆ Low energy cost
  - ☆ Low reaction volume
  - ☆ Waste valorization

Phase diagram of pure water



- Diphasic processes
- Monophasic processes

ICMCB research : recent development

> 1990 - 1994 : L'Electolyse (Bordeaux - France)

Batch experiments : reduction / oxidation
(200cc, 100MPa, 600°C)

> 1994 - 1997 : L'Electolyse (Bordeaux - France)
Aquitaine region
ADEME

Continuous reactor : reduction / oxidation
(3 kg/h, 50MPa, 600°C)

> 1998 : L'Electolyse (Bordeaux - France)
APESA (Pau - France)
Aquitaine region
DRIRE
Industrials (Elf, ...)

Industrial pilot plant : - multi-user
(100 kg/h, 50MPa, 600°C) - multi-effluent

Batch reactor

(200cc, 100MPa, 600°C)

> Oxidation :

☆ Well-known

☆ Do not take into account of hydrodynamics

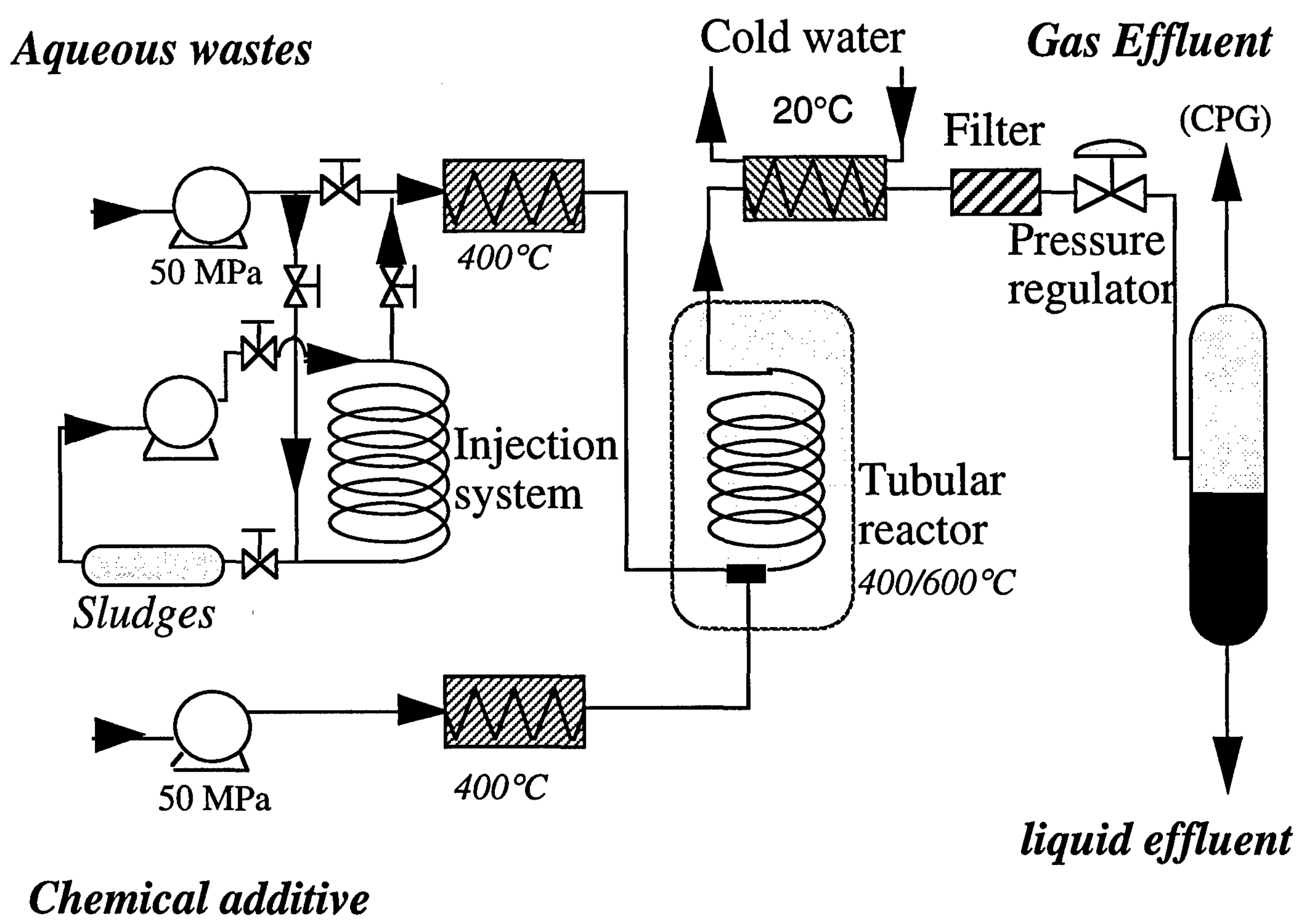
☆ Not representative of :

- very short residence time
- particles in suspension
- salt precipitation

Pilot plant facility

(3 kg/h, 50MPa, 600°C)

(PhD of Patrick BESLIN 1994-1997)



Pilot plant facility

(3 kg/h, 50MPa, 600°C)

- Injection :

☆ Validation

- Paper mill sludge
- Mechanical factory wastewater
- Emulsion

☆ Pseudo-continuous

sludge injection (10mn) / water injection (10s)

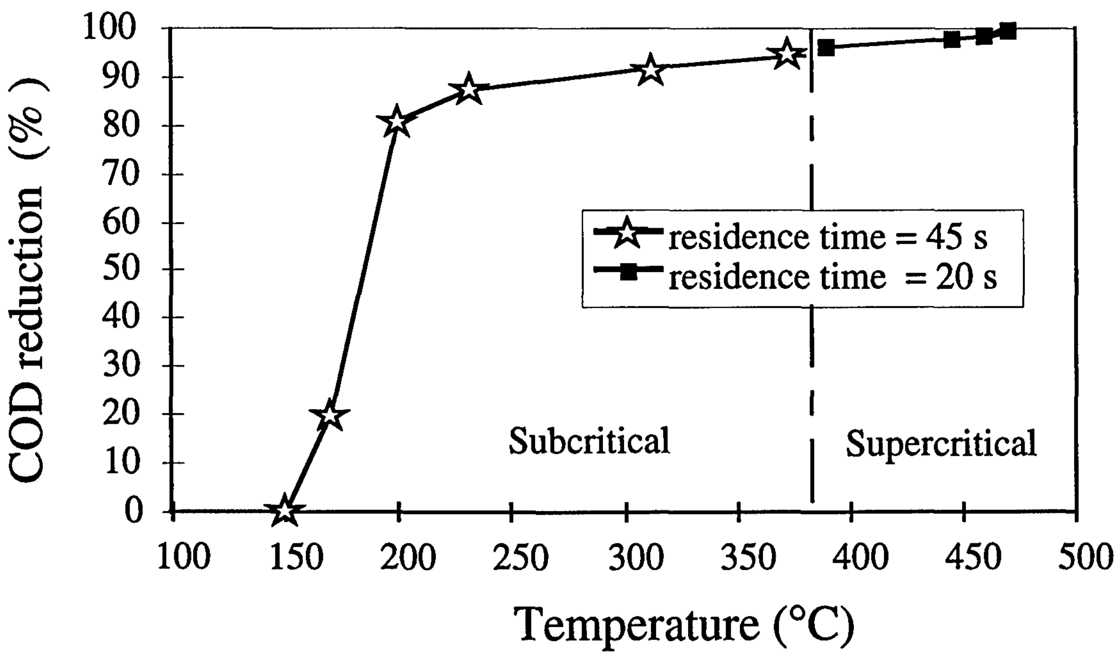
- Filtration : operating time of 6 hrs

Pilot plant facility

(3 kg/h, 50MPa, 600°C)

> Model compound :

- Glucose as wet cellulosic waste model
  - COD = 150 g/l
  - H_2O_2 excess = 65%
  - 25 MPa



Pilot plant facility

(3 kg/h, 50MPa, 600°C)

➢ Industrial validation : Paper mill sludge

- COD 14 g/l
- Total Suspension Solid 18 g/l
- Salt concentration 2.4 g/l
- Metal concentration 260 mg/l
- $[Cl^-]$ < 50 mg/l

T (°C)	Residence time (s)	TSS (mg/l)	COD (mg/l)	Conversion (%)
290	50	48	2600	76
440	50	32	530	94.7
505	50	9	80	99.3

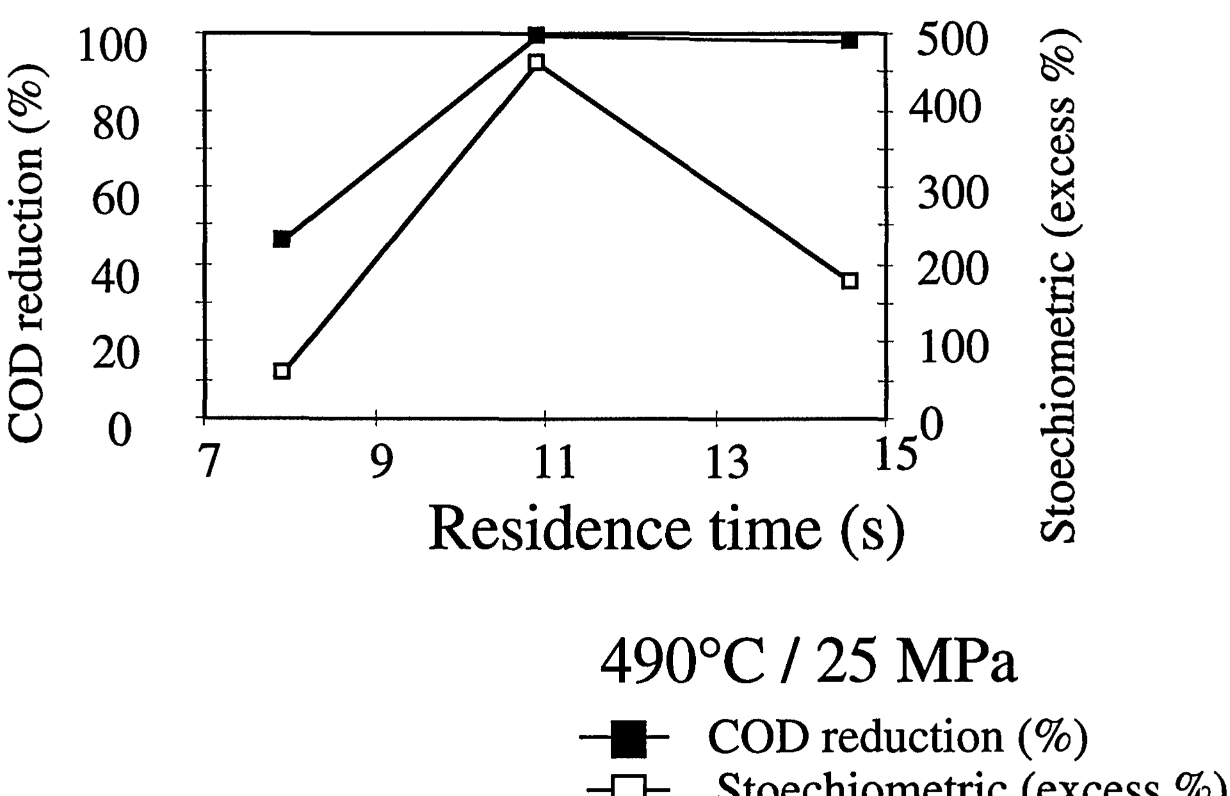
- H_2O_2 excess = 65%
- 25 MPa

Pilot plant facility

(3 kg/h, 50MPa, 600°C)

➢ Industrial validation : Mechanical factory wastewater

- COD	3.6 g/l
- Total Suspension Solid	1.1 g/l
- Salt concentration	300 mg/l
- Metal concentration	< 50 mg/l
- $[Cl^-]$, $[F^-]$	100 mg/l



Industrial pilot plant facility

(100 kg/h, 50MPa, 600°C)

- Pau - France
- Building in 1998
- Cost evaluation
- Multi-effluent
- Multi-user

- WAO / SCWO /SCWR
- high degree of instrumentation
- cost per day : 15-20 KF

French National Program

- ARC "Hydrothermal waste treatment"

  Coordinator : François CANSELL

action 1 : Brittleness of steel;

action 2 : Knowledge of general corrosion;

action 3 : New concept of reactor with cold wall;

action 4 : Modeling and simulation of transfers and hydrodynamics.

Session 5 – Working Groups

Summary

Working Group 1: Technical risk assessment and future research
Chairman: Dr. William Randall Seeker
Energy & Environmental Research Corp., USA

Working Group 2: Adaptation of current and future technologies to naval vessels
Chairman: Christoph Otten
Office of Military Technology and Procurement, Germany

Working Group 3: Policies and recommendations on international collaboration
Chairman: Dr. Kevin Whiting
Environmental Technology Consulting, UK

Summary

Working Group 1 (WG 1) identified the drivers and influencing factors for shipboard thermal waste treatment technologies, such as mission and manning requirements, the need to become independent of shore facilities and health and safety targets to be met.
General technology risks for thermal treatment technologies were pointed out ranging from public acceptance and perception to system design and automation.
WG 1 then discussed each of the three technology areas in turn and identified the benefits, risks and RD&D and engineering needs for each of them.
Its overall perception is, that the technology is there or at least feasible, but with a different degree of applicability for naval shipboard use. The furthest advanced is conventional incineration technology, which has been successfully installed aboard most cruise liners. However it also needs considerable development regarding its application and integration on naval vessels.

WG 2 assessed the adaptation of current and future thermal treatment technologies and their integration on naval vessels for waste treatment. The group considered navy unique requirements (space, weight, mission, operating cycles etc.) and identified available conventional incineration and storage technology as a reference to compare integration aspects of future technologies, like Plasma treatment and Super Critical Water Oxidation. This led to the recognition of the driving critical aspects, such as power and energy requirements, size and weight,waste stream management, air emissions etc..
WG 2 recommended, that the adaptation of future technologiesshould focus on operability, environmental and design integration issues.

WG 3 discussed policies and recommendations for international collaboration in this field. The group rrecognized NATO SWG/12 as an important forum for environmental information exchange amongst NATO Navies.
Both WG 3 and WG 1 identified the need for increased communication between the Navies as customers, technical experts from the equipment manufacturers and system integrators.
They concluded, that continued investment in the development of novel technologies for naval applications is warranted, as thermal waste treatment aboard ships should significantly reduce cost for offload and special (costly) regulations in ports.
There is a clear need to harmonize waste treatment requirements amongst NATO Navies and to cooperate with other international fora, like the EU Commission, to identify future trends in environmental regulations, that may impact naval vessels, at an early stage.
When requirements are sufficiently harmonized, cooperative development should be pursued to reduce risk and save time and money, especially under the current budget situation in most NATO countries.

In summary, the Working Groups established, that

- thermal waste treatment technology is available with varying degrees of maturity,
- international regulations will continue to evolve ever more stringent as technology matures, however individual port regulations will develop in a rather more diversified manner, making it difficult to comply and to retain operational freedom,
- naval vessels have special requirements regarding technology application and integration,
- manning, mission, availability, reliability and safety aspects will be drivers for the technology development,
- collaborative development of novel thermal waste treatment technologies and systems is worth pursuing by NATO Navies,
- regular workshops, like this one, should be held to increase and broaden the information exchange between the customer navies and producers and system integrators.

Session 5 – Working Groups

Working Group 1

Technical risk assessment and future research

Chairman: Dr. William Randall Seeker

Energy & Environmental Research Corp., USA

Technology Risk Assessment and Research Needs

1. Drivers and Influencing Parameters for ship board treatment technologies

- Need to attain independence from shore due to port reception facilities, political issues and disposal requirements at Ports which dictate costs and potential to hold ships "hostage"
- Health and safety targets as an ultimate driver.
- Mission consistent with military operations first dictates competition for space and weight on the naval vessel
- Likelihood of application of ship board treatment increases dramatically for new platforms as opposed to retrofit of older ships.
- Policy and schedules for compliant fleet (e.g., UK compliant ship by 2005)
- Laws and regulations for water and air discharges
  - IMO standards. General stable set of rules that can be met by some treatment technologies.
  - Port specific requirements dictated by federal, state and local requirements. Port specific requirements can be a moving target. Need to make the policy makers informed about the cost and realities of meeting these port specific requirements
  - May have to focus on problematic wastes streams for the port specific requirements
  - long range research target is land based thermal treatment standards
- Costs of technology development, application and use
- Schedule for deployment

- Compatibility for flexible operation and missions within the ship board environment
- Minimal manning requirements by sailors
- Maintainable and reliable.

2. General Technology risks for thermal treatment technologies

- public acceptance and perception
- waste materials handling and feed systems and waste stream management and variability
- compactness: size and weight for throughput rates
- sailor operating training
- future system design and platforms
- maintenance and reliability
- continuous performance assurance
- life cycle engineering for systems that might be operated for decades.
- development of land based equivalent performance with ship board compatibility.

3.0 Incineration Specific Benefits, Risks and R,D&D and Engineering Requirements.

3.1 Benefits of Incineration

- Demonstrated and certified for IMO compliance
- Well established land based and Cruise Liner Experience

- Stringent land based environmental requirements is technology forcing and new systems are emerging
- Waste flexible and waste compatible

3.2 Risks of Incineration Technology for Naval applications

- Public acceptance and perception
- Ash and secondary wastes
- Size and weight for throughput
- Sailor operator training requirements
- Maintainability and reliability

3.3 RD&D and Engineering Needs

- Automatic operation
- Operator Interface
- Compactness improvements and optimization using techniques such as acoustics, oxygen enrichment, radical generation, modular component development, thermal recovery and managements, etc.
- Continuous performance assurance (CEMs, process monitoring and control)
- Development of Equipment for ship board applications that has the technically equivalent performance of land based systems such as air pollution control.
- Life cycle engineering for long life operation
- feed systems and materials handling

4.0 Plasma Specific Benefits, Risks and R,D&D and Engineering Requirements

4.1 Benefits of Plasma Treatment Technologies

- Potential for meeting IMO compliance (not yet demonstrated)
- Waste flexible and versatile
- Maximum volume reduction of solid
- Ash vitrification and benign solid product
- Electrical based system compatible with all energy systems
- Potential for compact high throughput rates
- Gas volume reduction with low excess air

4.2 Technology Risks of Plasma Treatment Technology for Naval Applications

- To date plasma technology is unproven for commercial treatment of waste even for land-based operation (Proven for other applications and some ongoing demonstrations for waste treatment)
- Ship board integration to minimize space and weight requirements for maximum throughput rates.
- Safety issues
- Electricity requirements for non-nuclear operation
- operability, reliability, and maintainability
- public perception is unknown but likely to be similar to incineration
- waste stream management and variability
- slag management
- operator training

- high temperatures and thermal management including materials of construction
- platform motion impacts

4.3 Plasma Treatment Specific Benefits, Risks and R,D&D and Engineering Requirements.

- Develop relevant full scale operating experience
- Similar research needs to incineration on continuous performance assurance
- Materials consistent with molten metal and high power densities
- Slag handling and management
- Torch reliability and lifetimes
- Flexibility for range of waste streams adds demands for air pollution control systems
- Engineering for avoidance of EMI
- Engineering for automation and sailor operator interface
- System integration developments such as platform motion, waste feed preparation
- Compactness improvements and optimization using techniques such as acoustics, oxygen enrichment, radical generation, modular component development, thermal recovery and managements, etc.

5.0 Supercritical Water Oxidation Specific Benefits, Risks and R,D&D and Engineering Requirements.

5.1 Benefits of Supercritical Water Oxidation Treatment Technologies

- Land based proven technology for simple waste streams although not ship board certified
- minimal secondary wastes depending on inorganic levels
- potential for small compact systems
- no uncontrolled releases
- potential for automatic operation
- potentially compatible with small ship applications
- Compatible with water based waste streams
- Low thermal energy requirements

5.2 Technology Risks of Supercritical Water oxidations Treatment Technology for Naval Applications

- Flexibility for wide range of variable waste streams
- Need scale up to application for ships while maintaining size and increasing throughput rates
- Not suitable for solid wastes due to significant pretreatment and segregation requirements
- Solid residual separation
- quenching process
- materials of construction particularly in the sea water environment
- compressor requirements
- safety perception
- maintainability and reliability

5.3 Super Critical Water Oxidation Treatment Specific Benefits, Risks and R,D&D and Engineering Requirements.

- Solid Residual Separation
- Compactness and throughput rates
- automatic control for waste stream variability
- salt and halogen management
- materials of construction
- alternative oxidants and reducers
- Byproduct control

6.0 Overall Recommendations

1. Technical community needs to play an active role in providing input to user community and environmental policy makers relative to technical realities of ship board waste treatment
2. Keep the technical base strong for treatment technology for the expected life cycle of the treatment technology
3. Technology developers need an early recognition of the Naval ship board requirements and to work with Naval architects on integration
4. Need to develop common data base and testing protocols for comparison of treatment technology performance
5. Research and developments must address the appropriate time frames for new platforms and compliance deadlines.
6. Need to prioritize RD&D items
7. This is a living document and needs to be reviewed and updated in the future as more information becomes available on ship board applications and treatment technologies.

<u>Session 5</u> – Working Groups

<u>Working Group 2</u>

Adaptation of current and future technologies to naval vessels

<u>Chairman</u>: Christoph Otten

Office of Military Technology and Procurement, Germany

WORKSHOP ON THERMAL WASTE TREATMENT

WORKING GROUP 2 ON ADAPTATION OF CURRENT AND FUTURE THERMAL TREATMENT

GOAL

- To explore areas for future consideration regarding the adaptation of current and future thermal treatment technologies to navy vessels for waste treatment.

Starting point for discussion

- Marpol Annex VI compliance
- additional navy unique requirements
- available technology
  - conventional incineration
  - storage

Integration issues of incinerators

- Shock class B can be met
- IR signature requirements can be met
- NBCD aspects needs design consideration
- Waste differences commercial vs. navy
- add. operational requirement
  - flight operations -> dust emissions

Integration issues of storage

- Space requirements
- Operational limitations (example frigate)
- Offload of wastes -> back-RAS

Recommendation: Navies should address the viability of back-RAS in terms of operability and safety.

Integration issues of new technologies

- Comparison of incineration vs. Plasma Arc Pyrolysis (SCWO not considered due to time constraints)
- Critical Aspects
  - Power and energy requirement
  - Size and weight
  - Types of waste to be handled
  - Air emissions
  - Disposal of ash vs. slag

Final Result

Integration aspects of all technologies require further consideration . Therefore the adaptation of current and future technologies should focus on

- operability
- environmental
- and design integration issues.

<u>Session 5</u> – Working Groups

<u>Working Group 3</u>

Policies and recommendations on international collaboration

<u>Chairman</u>: Dr. Kevin Whiting

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Working Group Three
Policies and Recommendations on International Collaboration

Conclusions:

1. NATO Special Working Group 12 on Maritime Environmental Protection is recognized as an important forum for environmental information exchange by the NATO navies.

2. If marine thermal treatment devices are intended to be used in ports, it is likely that most European nations will require these devices to meet the most stringent land based incinerator air emission standards. The decision to use, or not to use, thermal treatment systems in ports may become a key requirements driver when selecting technologies for implementation in navy ships.

3. Future cooperation in thermal treatment technologies for naval application will be dependent on agreeing a common requirement. This potential for developing a common requirement is dependent on the degree on commonality among international, national, and local regulations.

4. Increased communication between the navies as customers, technical experts from industry and academia, and industrial producers and systems integrators is required.

5. Continued investment in novel thermal treatment technologies including advanced incineration, plasma arc and supercritical water oxidation for naval applications is warranted. SWG/12 should be made aware of the technology gaps, development required, time scales and costs needed to progress these technologies to the point where they may be implemented on navy ships.

6. Thermal treatment of wastes on board ships should reduce the costs of offload in ports.

7. Pre-treatment or waste sorting decisions could significantly impact the ability to integrate waste processing systems.

8. At the current state of the art, advanced thermal destruction technologies are not sufficiently mature nor automated sufficiently to permit operation by minimal skill level personnel. This may lead to impacts on manning, training, and reliability. Investment in further development will be required to reduce these risks. However, these objectives will increase development and procurement costs.

9. The advanced thermal destruction technologies examined by this workshop show varying potential for further size reduction and throughput enhancements. When this work is completed, these technologies may developed into equipment that is suitable for backfit as well as new design ships. The decision to backfit will be driven by cost benefit criteria.

Recommendations:

1. NATO Special Working Group 12 on Maritime Environmental Protection should establish liaison/dialog with European Union Groups DG7 (International Maritime Regulation for International Transport) and DG12 (Environmental Regulations) to enhance SWG/12's knowledge of future trends in environmental regulations that may impact navies.

2. Future marine thermal treatment air emission regulations should be based on best practicable technologies for naval ships.

3. Increase use of the Internet, conferences, newsletters, and professional meetings to share relevant information. Develop this workshop into an annual technical workshop to increase the dialog between customers, developers, and suppliers and identify opportunities for cooperation.

4. When requirements are sufficiently harmonized and in light of reduced funding in national budgets, cooperative development should be pursued to reduce risk to save time and money.

5. The decision to use thermal treatment technologies should be made very early in the ship requirements definition process and integrated into the ship design at the earliest possible time.

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